Extreme SC Proton Linacs: Issues, Strategy and Prospects; ESSnuSB

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Beam Physics and Operations
European Spallation Source

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Accelerator Buildings: Site

Accelerator Buildings: Site

Accelerator Buildings: Site

Accelerator Buildings: Tunnel

Accelerator Buildings: Gallery

Top Level Parameters

Design Drivers:

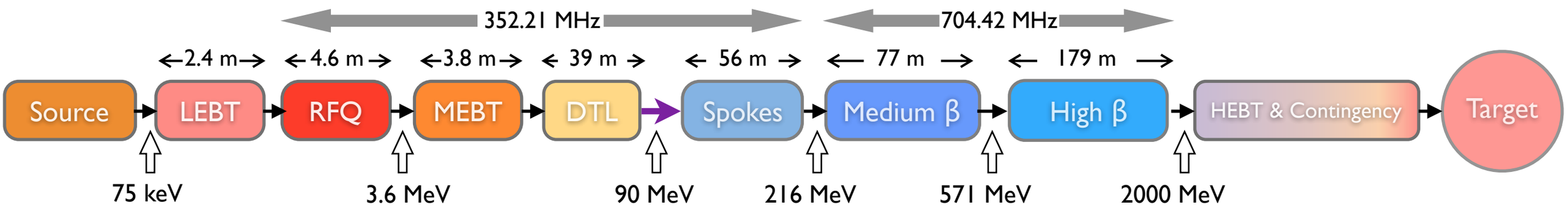
High average beam power	5MW
High peak beam power	125 MW
High availability	>95 %

Key Linac parameters:

Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions	p

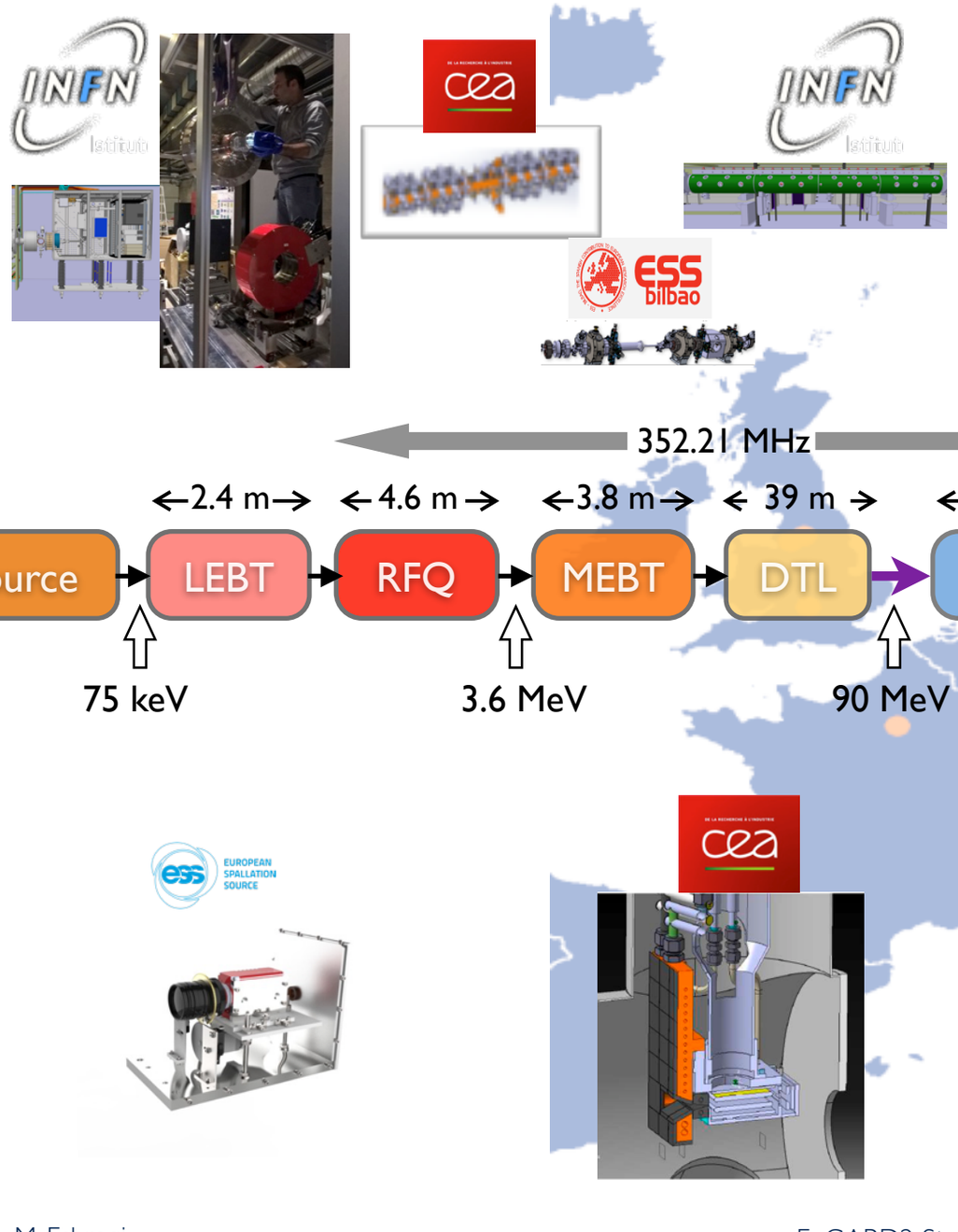
Flexible/Upgradable design

Minimize energy consumption

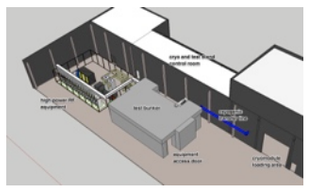


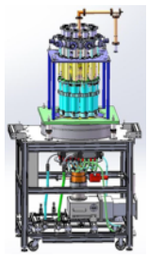
First beam at 571 MeV ready in June 2019,
Full energy/full power planned for 2023

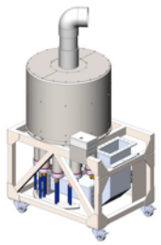
EuCARD² Accelerator Collaboration: Tunnel

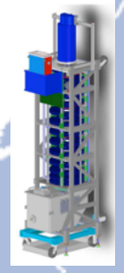


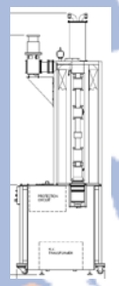
Accelerator Collaboration: Gallery

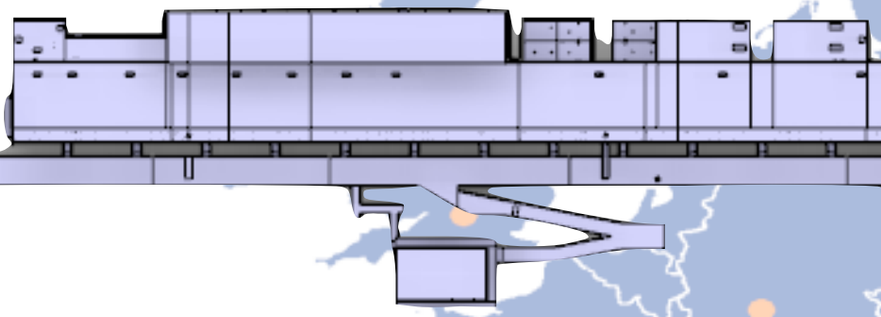


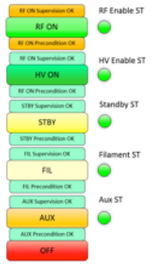


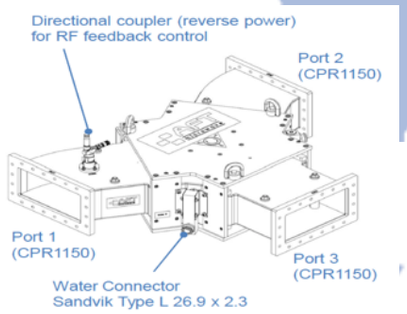


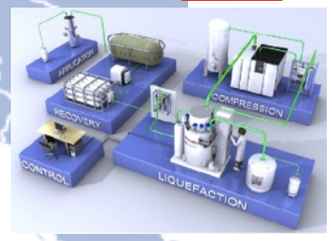


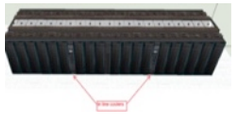






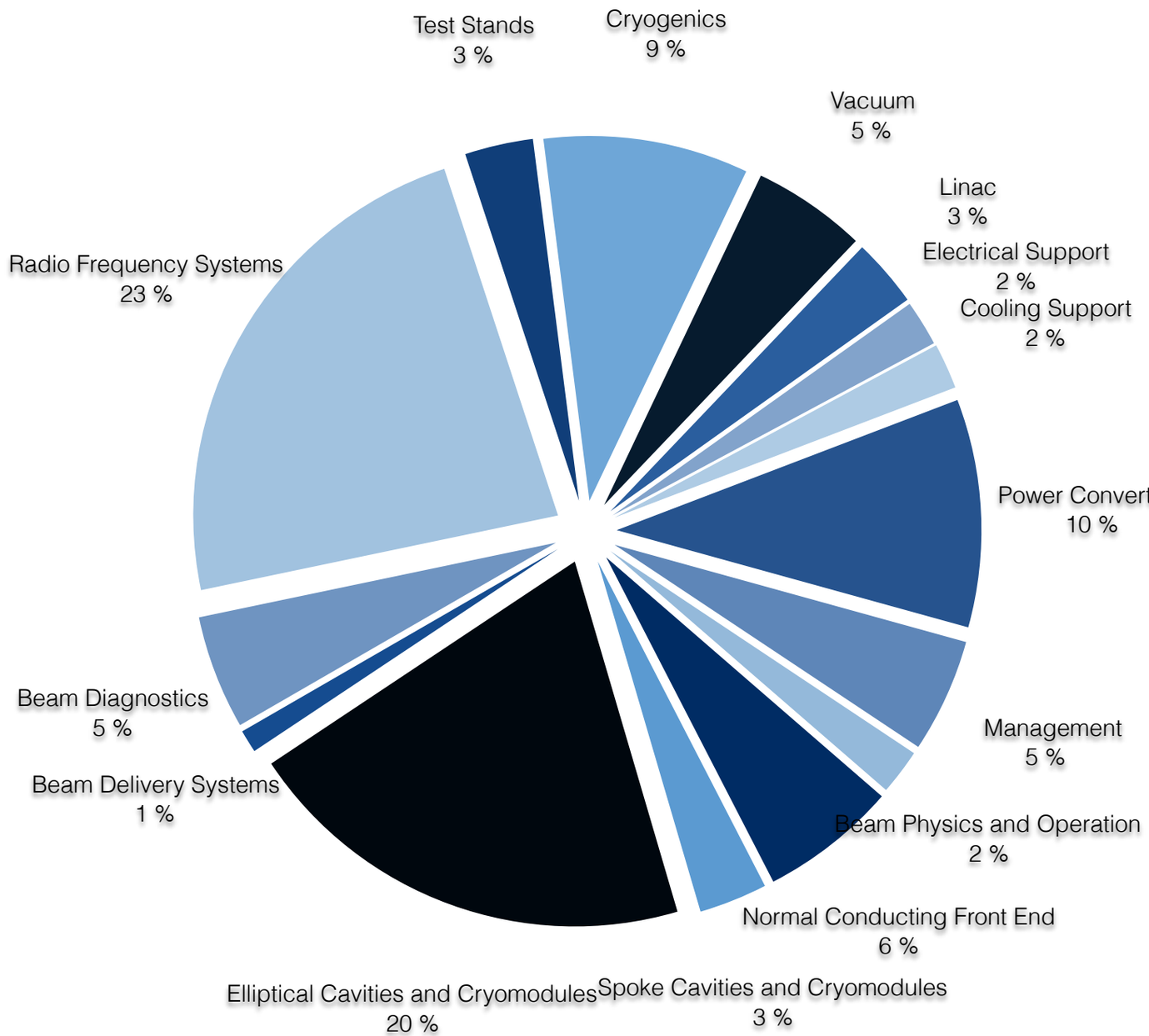






Concept, courtesy of GRE (UK)

Cost per Work-package



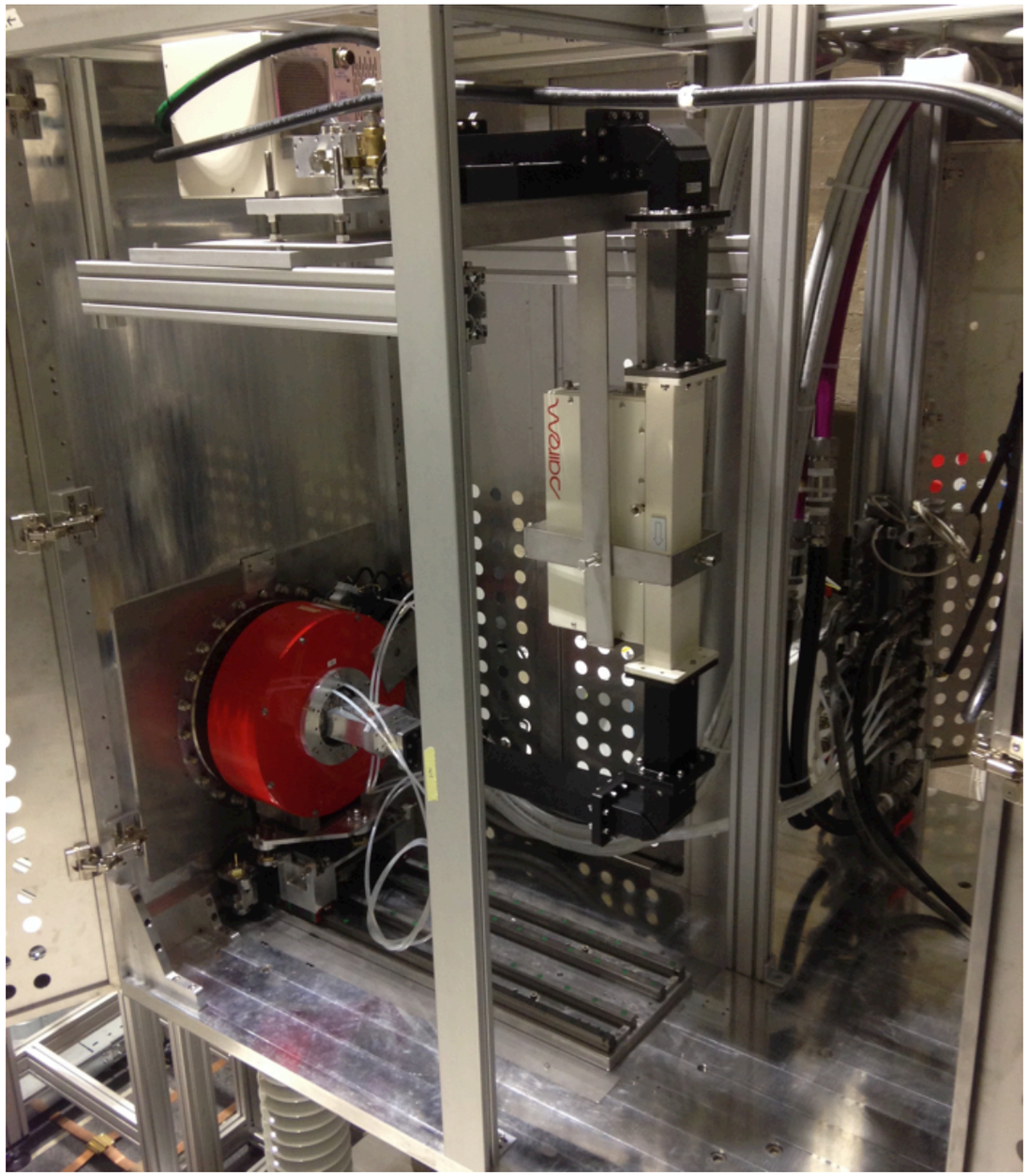
ESSnuSB upgrade Cases

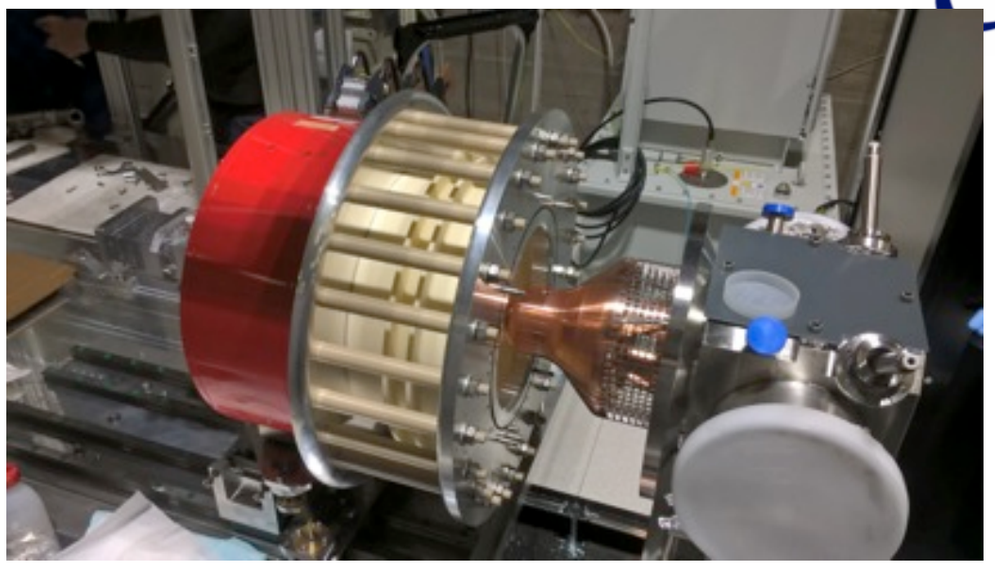
- Scenario I
  - The ESSnuSB requires the ESS linac to provide an additional 5 MW of beam power, there are two scenarios being discussed for the additional 5 MW:
    - 28 Hz:
      - 14 Hz for neutron production + 14 Hz for neutrino production (5 MW to each destination)
    - 56 Hz:
      - 14 Hz for neutron production + 42 Hz for neutrino production (5 MW to each destination)

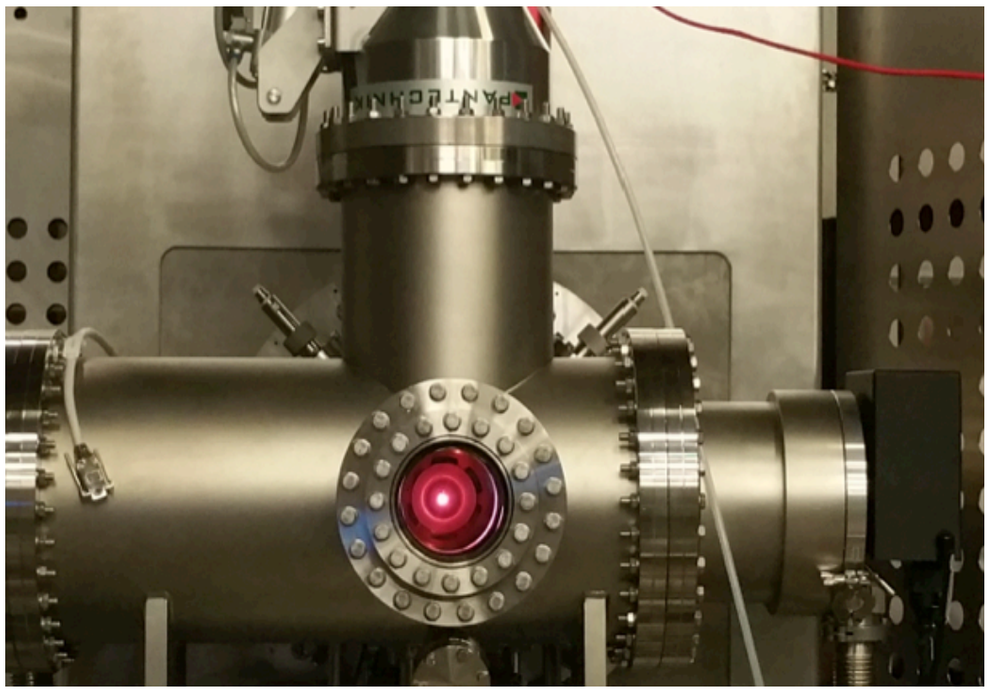
- Scenario II
  - Any energy upgrade beyond 2 GeV will simplify the delivery of a second 5 MW beam from the ESS linac.
    - With the energy upgrade to 2.5 GeV the increase of average power needed from the nominal Radio Frequency (RF) stations is ~60%, which looks feasible within the existing RF gallery space.
    - An energy upgrade to 3 GeV would further decrease the need for higher RF power from the existing stations to ~30%.
  - The high-beta superconducting cavities have a total filling time of around 0.3 ms, and for a beam duty cycle of 8%:
    - 28 Hz yields an RF duty cycle of 8.4%
    - 56 Hz yields an RF duty cycle of 9.45%

Extracted from the report by Frank Gerigk and Eric Montesinos, CERN-ADD-NOTE-2016-0050

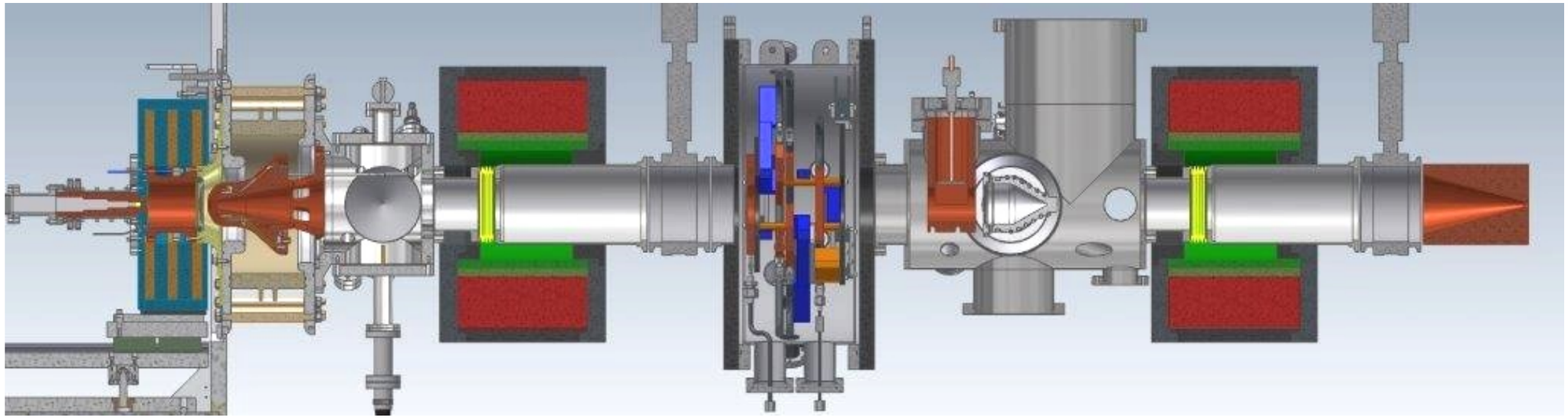
Ion Source: Microwave Discharge Ion Source

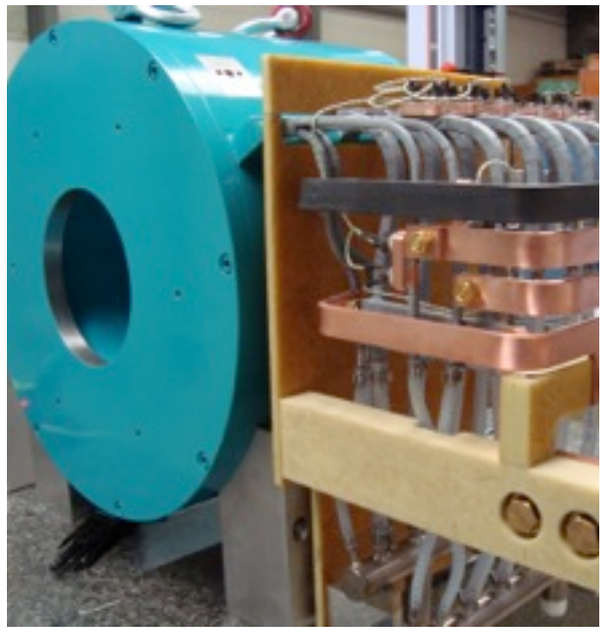




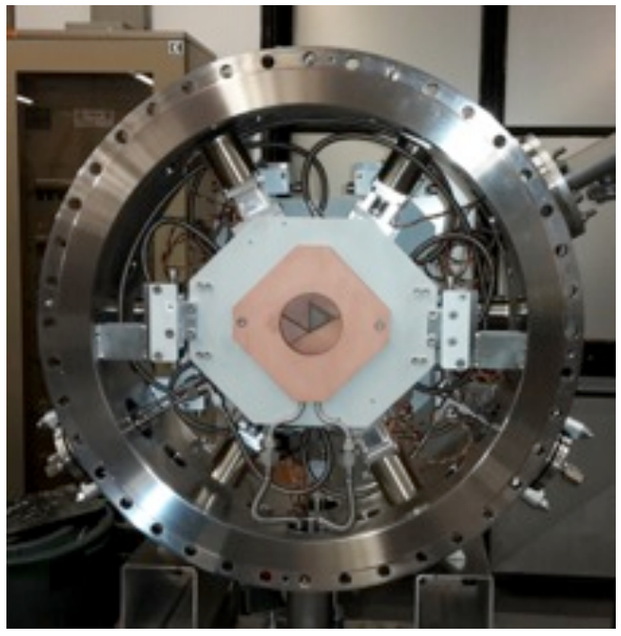


LEBT

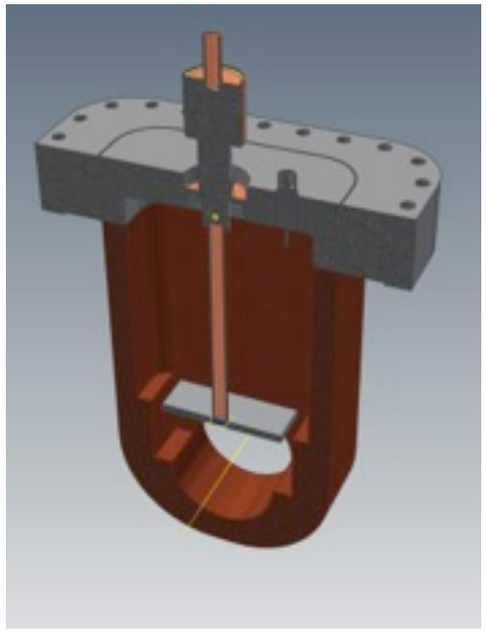




Solenoid



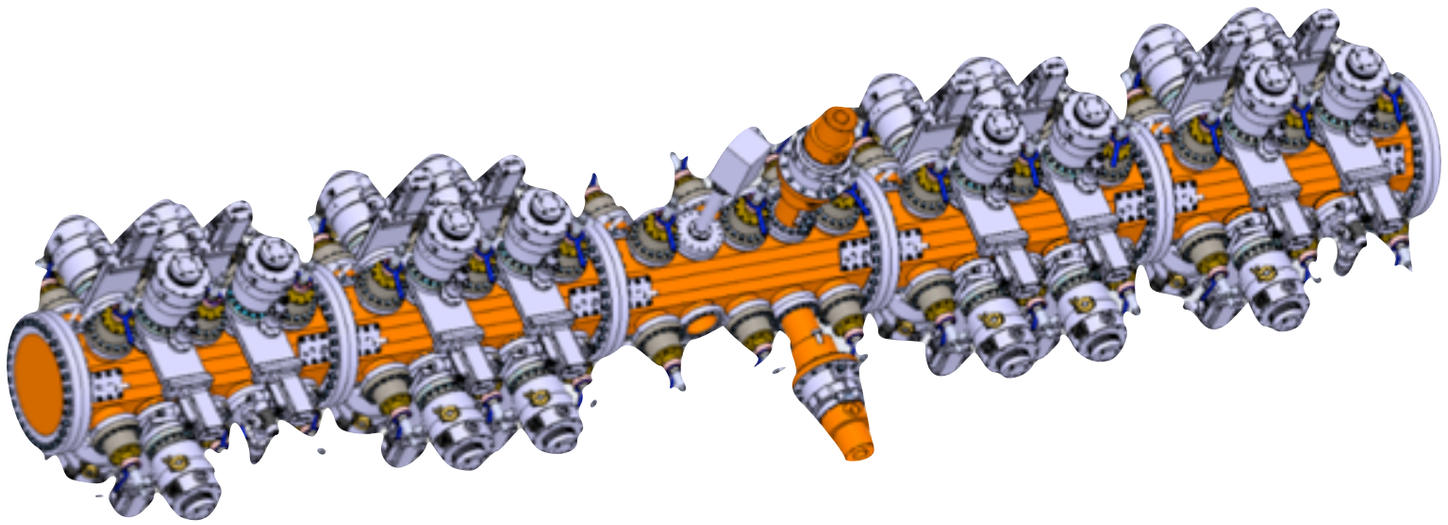
Iris

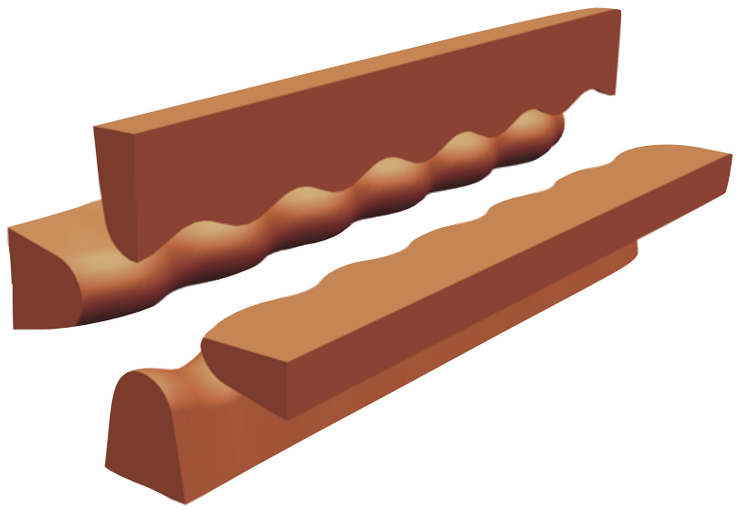


Chopper

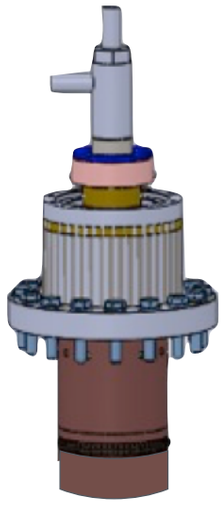
RFQ

- Accelerates the beam from 75 keV to 3.62 MeV

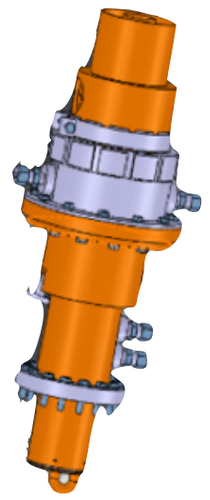




4 vane RFQ



Tuners

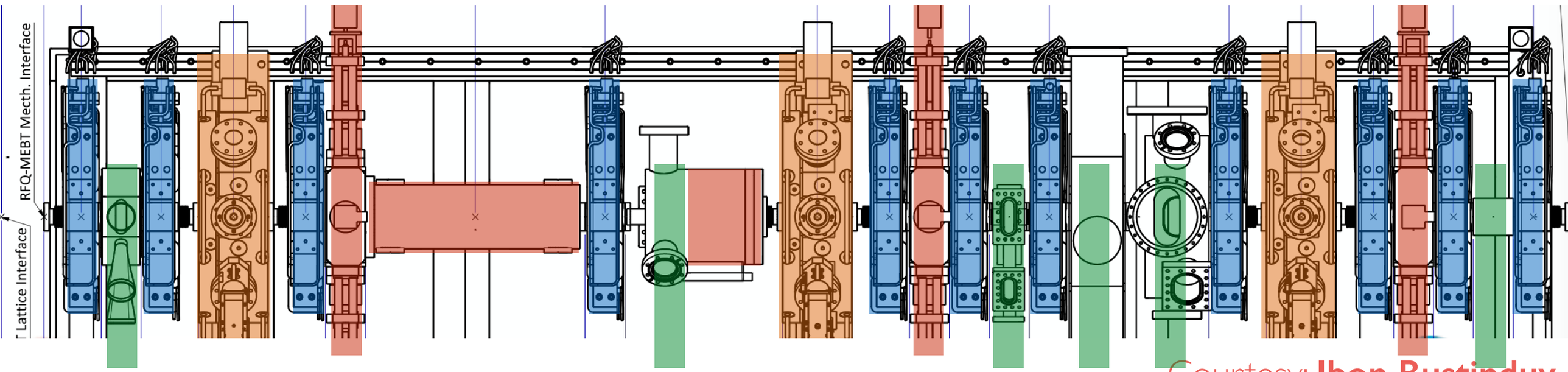


RF coupler

MEBT I

- Match RFQ output beam to the DTL (Three planes)
- Characterise the beam (Three planes)
- Clean the head of pulse using a fast chopper
- Clean the transverse halo using scrapers

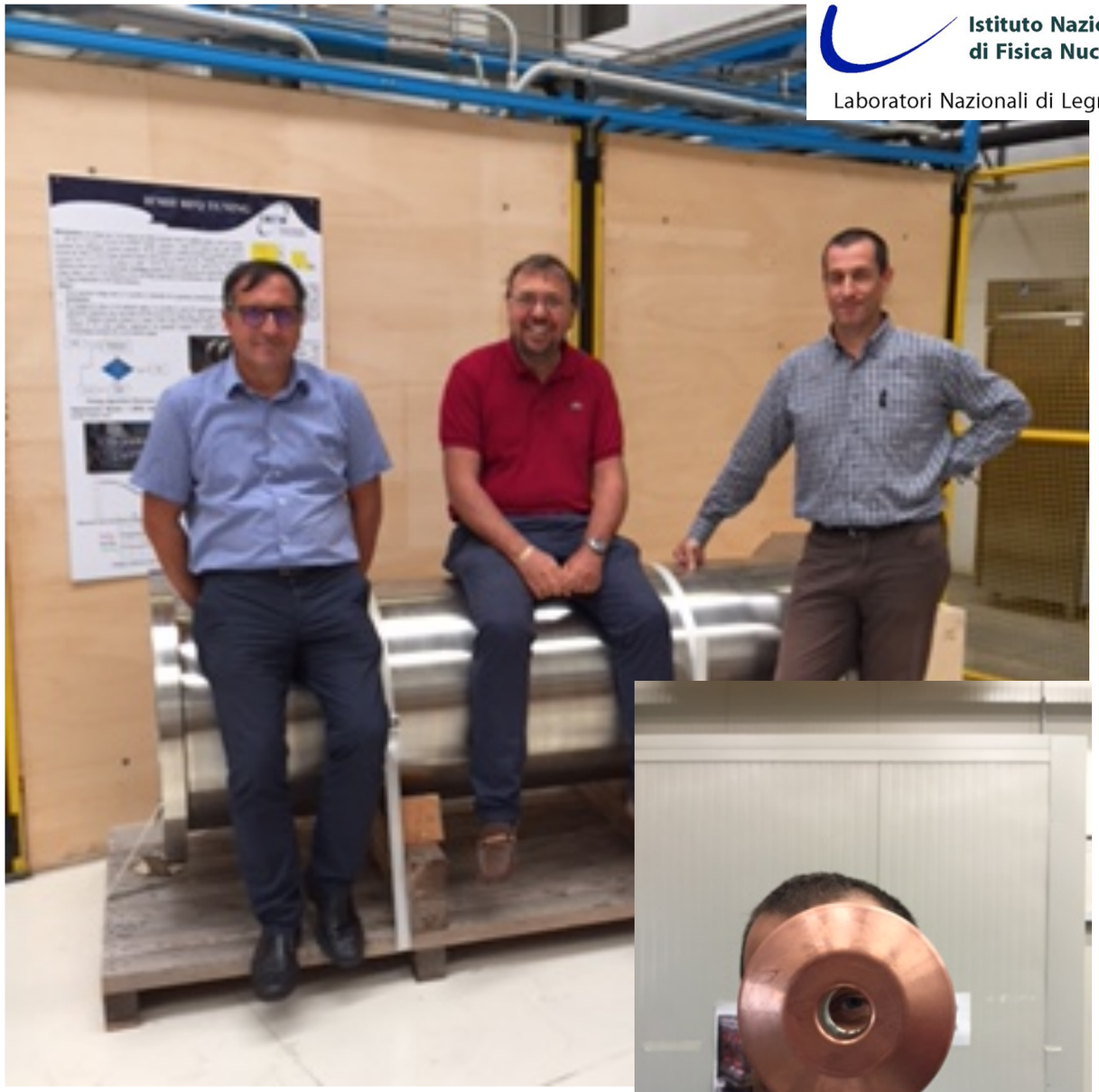
QUADs/Correctors, Cavities, Measurement Devices, Cleaning Devices



Courtesy: **Ibon Bustinduy**

https://indico.esss.lu.se/event/406/session/8/contribution/18/material/0/0.pdf

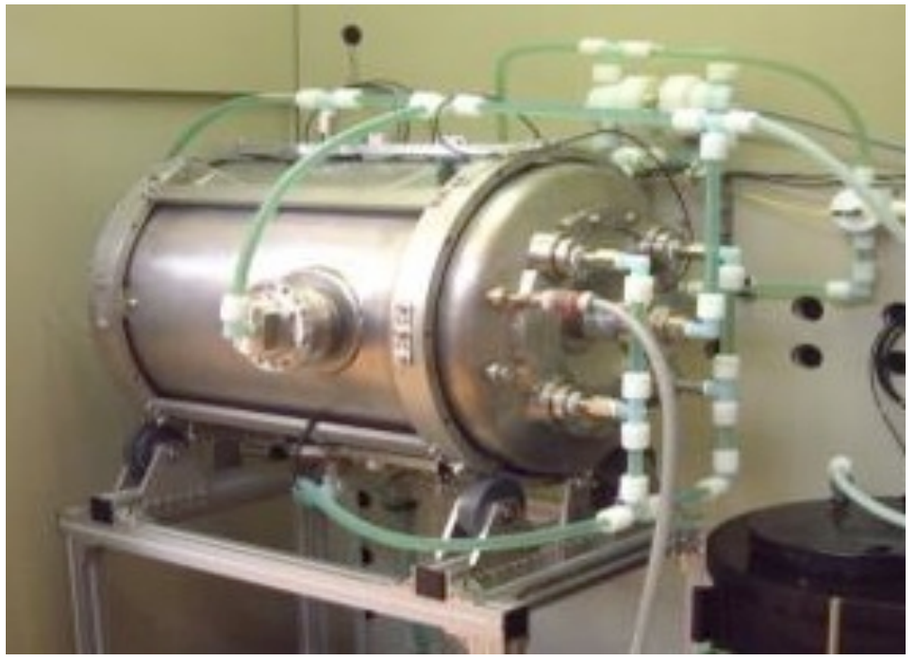
Progress on DTL



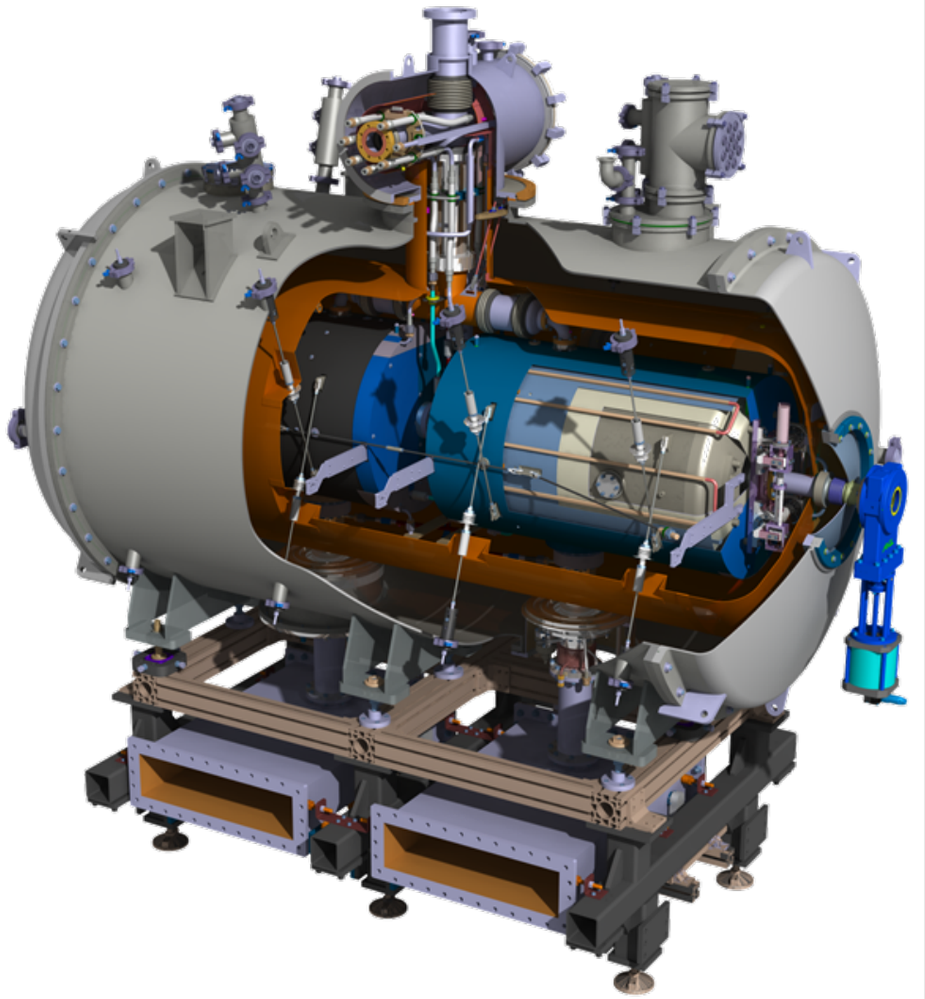
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

SPOKE

- Quadrupole Doublet Focusing (DC Quad and Corrector)
- Starts with a differential pumping section (LEDP)
- Accelerates the beam from 90 to 216 MeV
- Double spoke, βopt = 0.5, E_{acc} = 9 MV/m



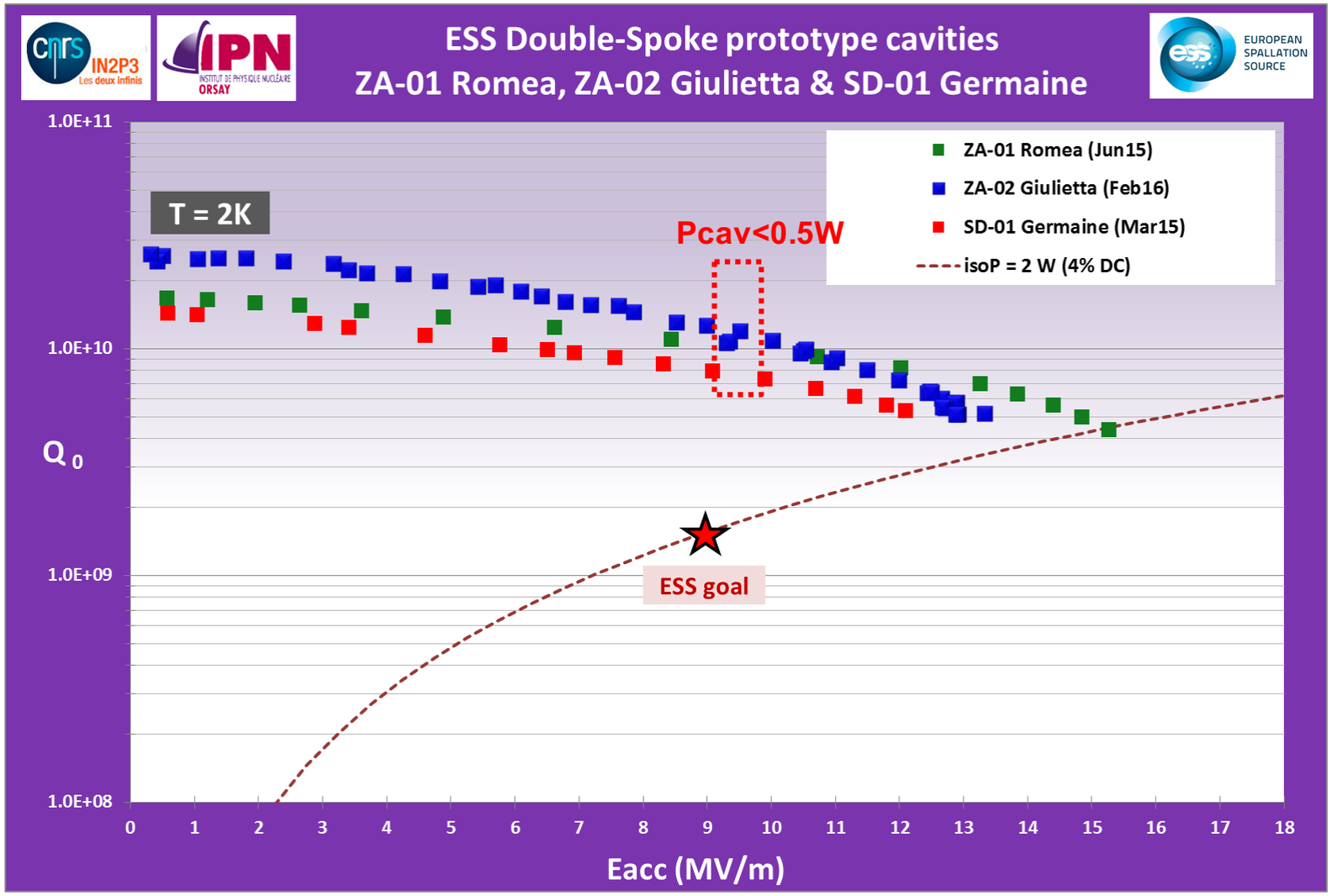
13 × Spoke

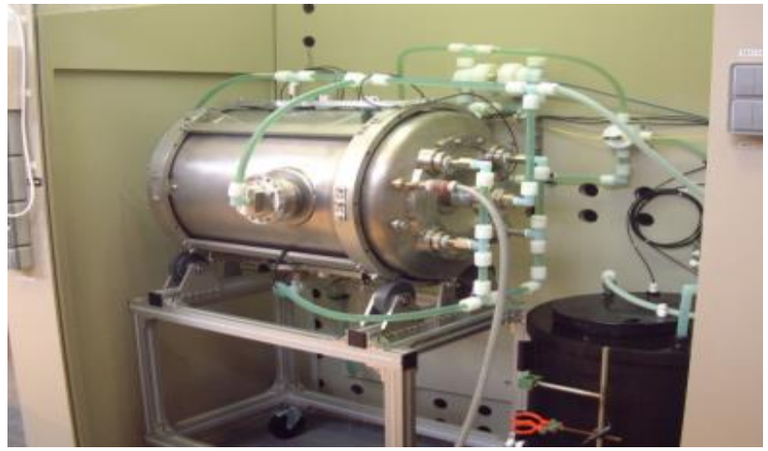


ESS Spoke cryomodule with two double spoke cavities, and two power couplers

Spoke Prototype Performance

- Spoke cavity prototype test results (Jan15 – Feb16):
  - Excellent performances, well within specifications (both on E_{acc} & Q_0)



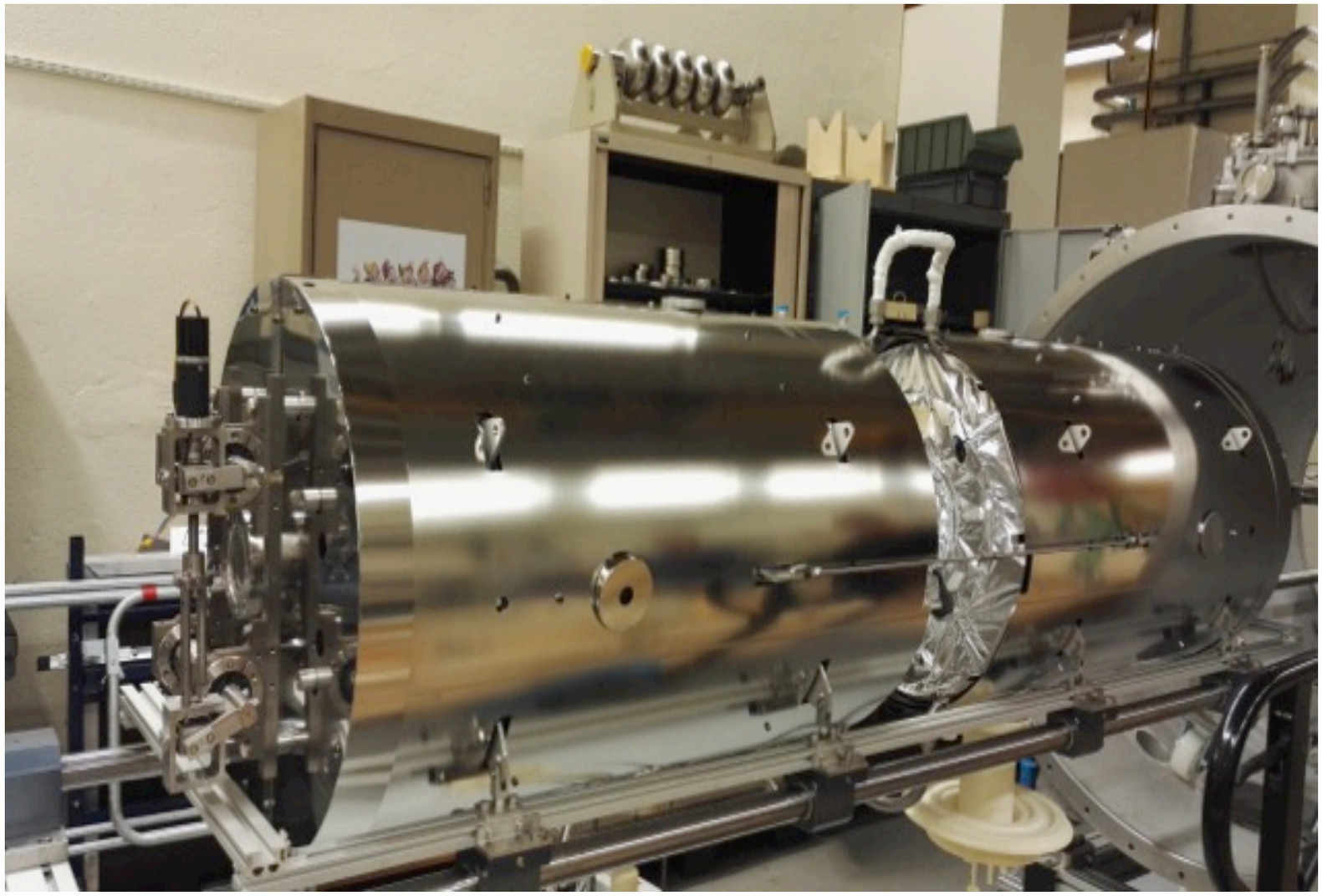


Chemical Etching

Ultra pure water high pressure rinsing

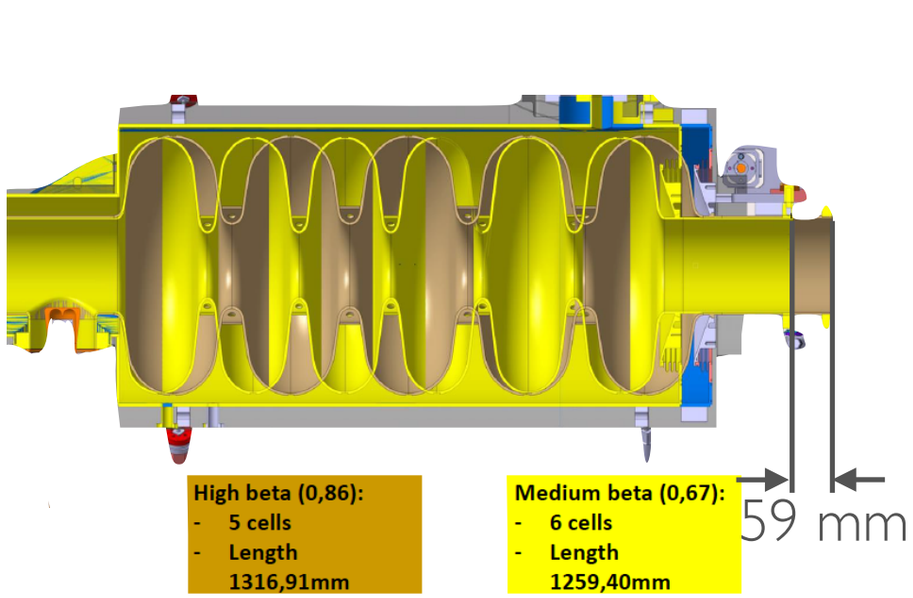
Spoke Highlights

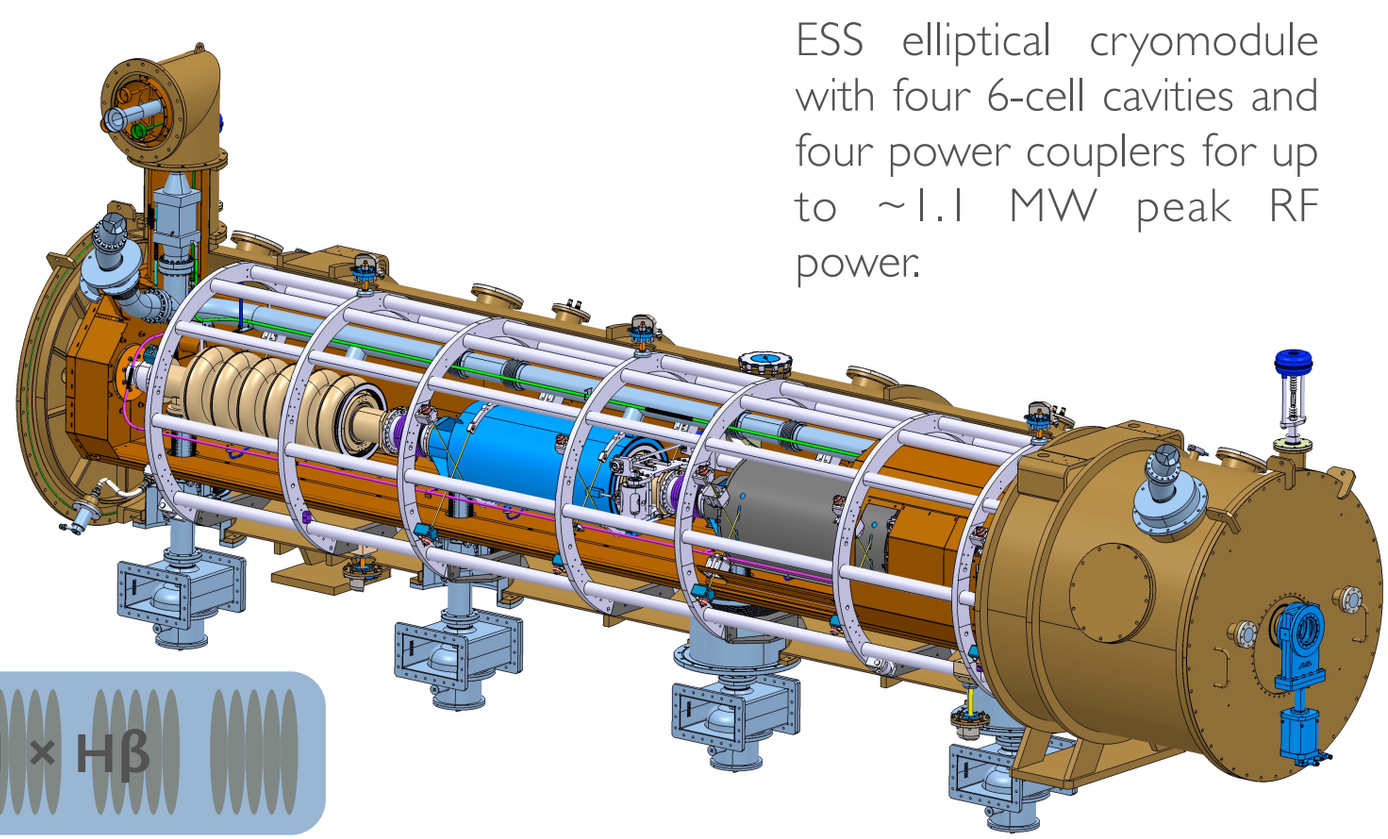
- WP4 Spoke Cavities and Cryomodules
  - First assembly of the cryomodule



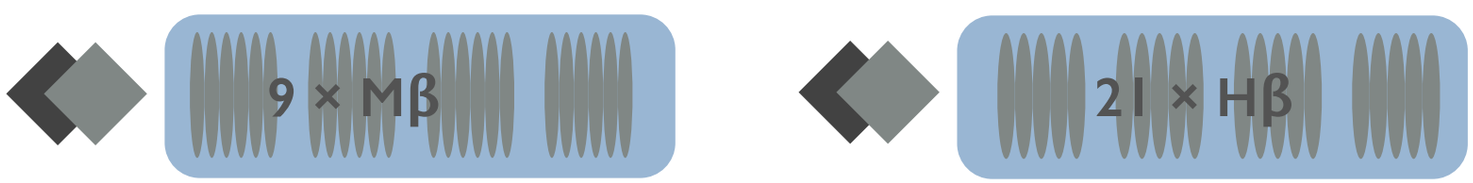
ELLIPTICALS

- Quadrupole Doublet Focusing
- Accelerates the beam from 216 MeV to 571 to 2 GeV in Two families:
  - 6-cell, $\beta g = 0.67$, $E_{acc} = 16.7$ MV/m
  - 5-cell, $\beta g = 0.86$, $E_{acc} = 19.9$ MV/m



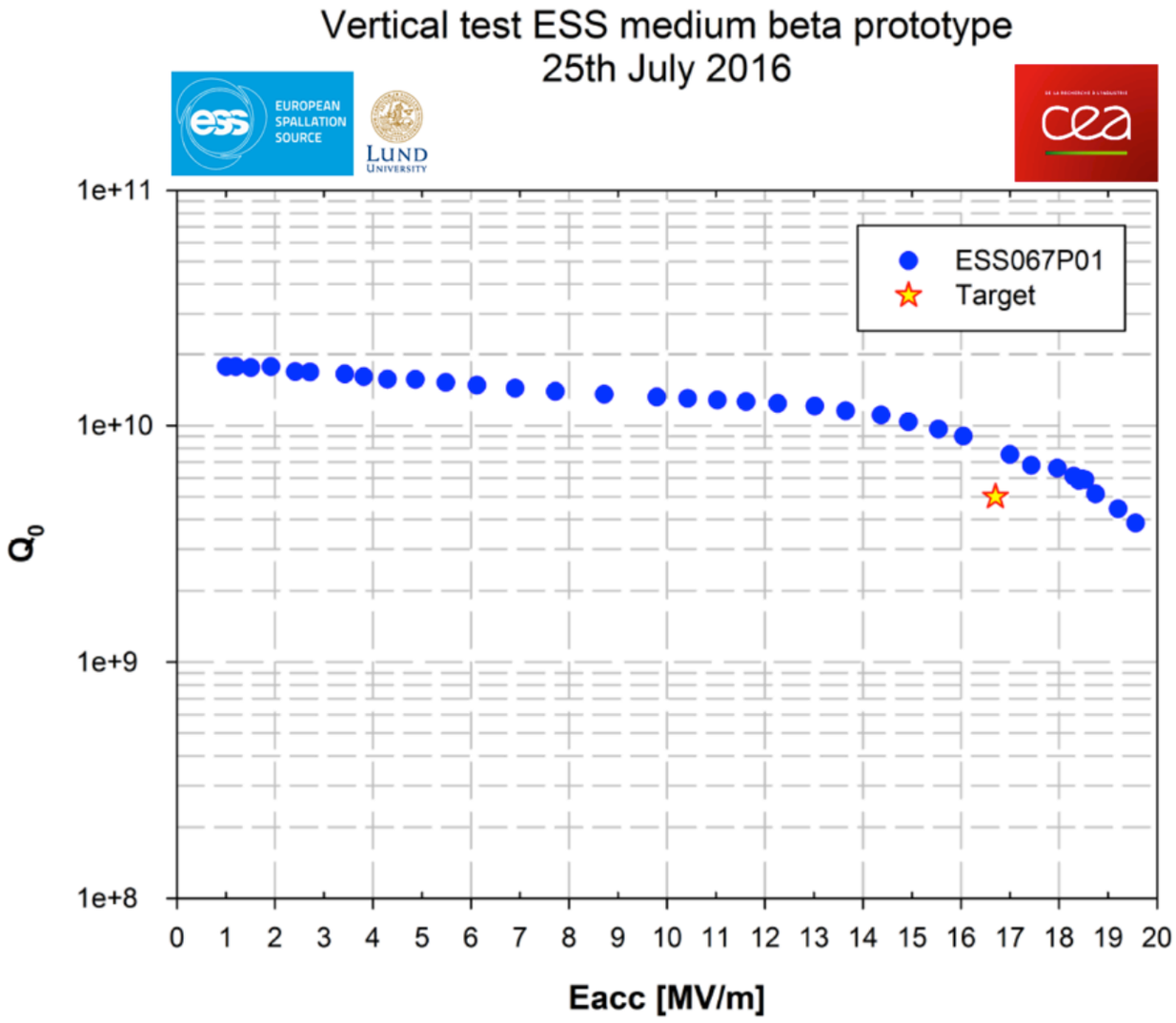


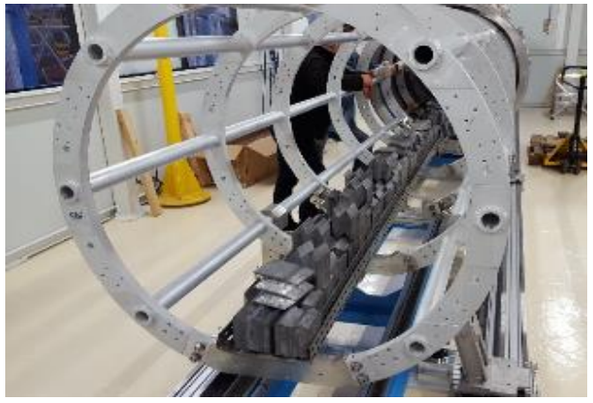
ESS elliptical cryomodule with four 6-cell cavities and four power couplers for up to ~1.1 MW peak RF power.



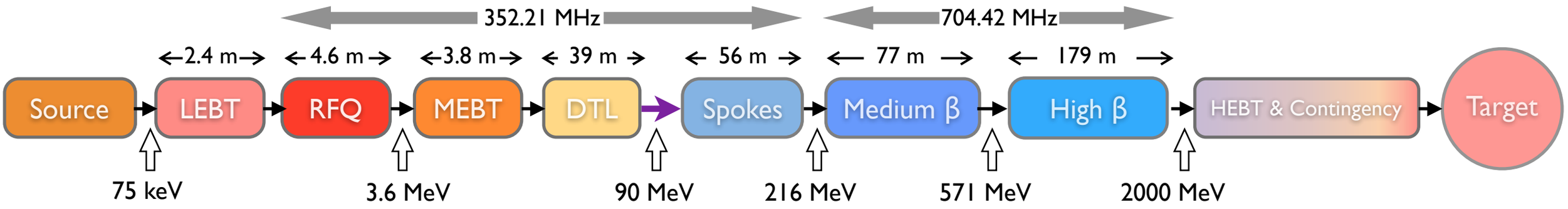
ELLIPTICALS HIGHLIGHTS

- WP5 Elliptical Cavities and Cryomodules:
  - Medium Beta P01 Cavity result





ESSnuSB



H- source

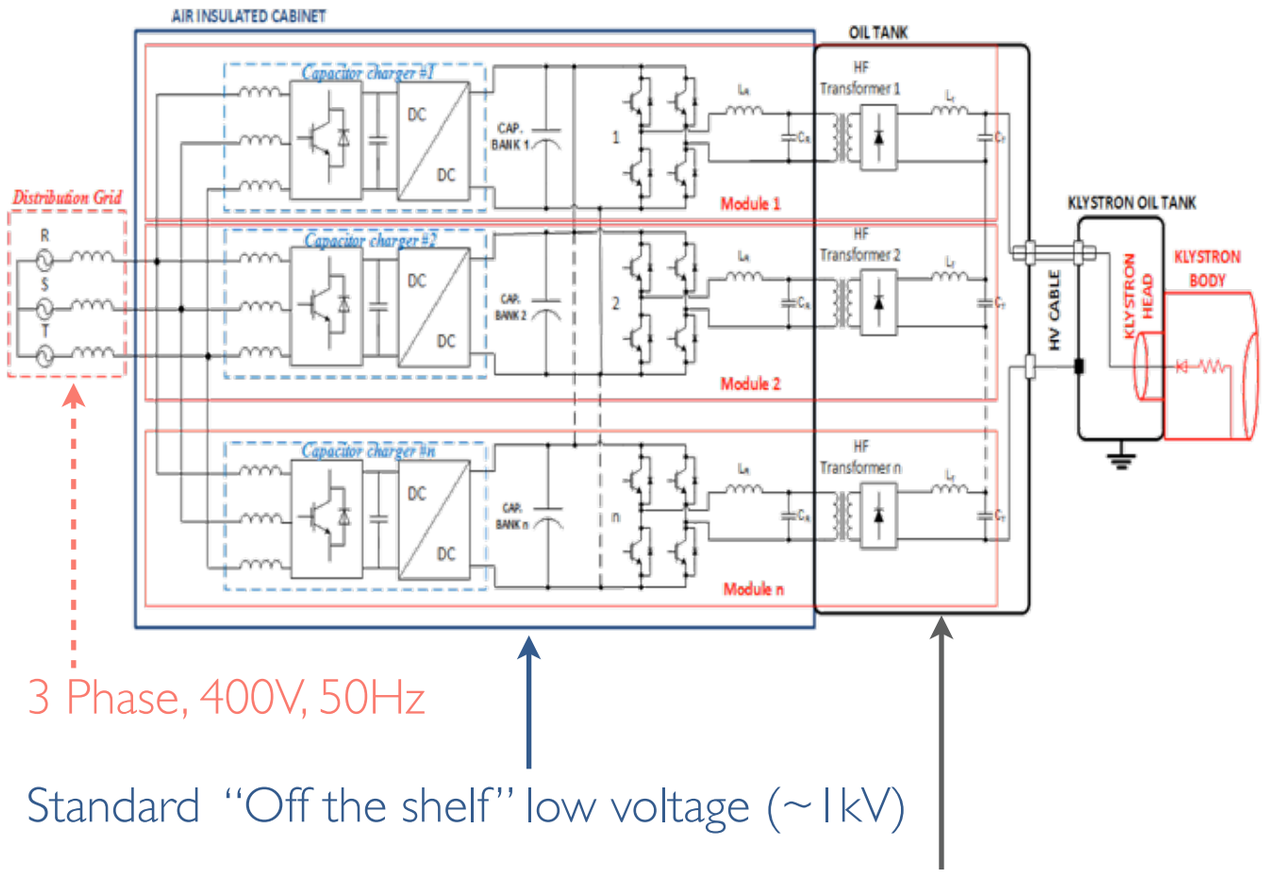
SC cavities (couplers, cavities)

RF (Modulators, SSA, Tubes), LLRF

Beam physics (Halo, losses)

Operations, Reliability, Availability

RF Generation

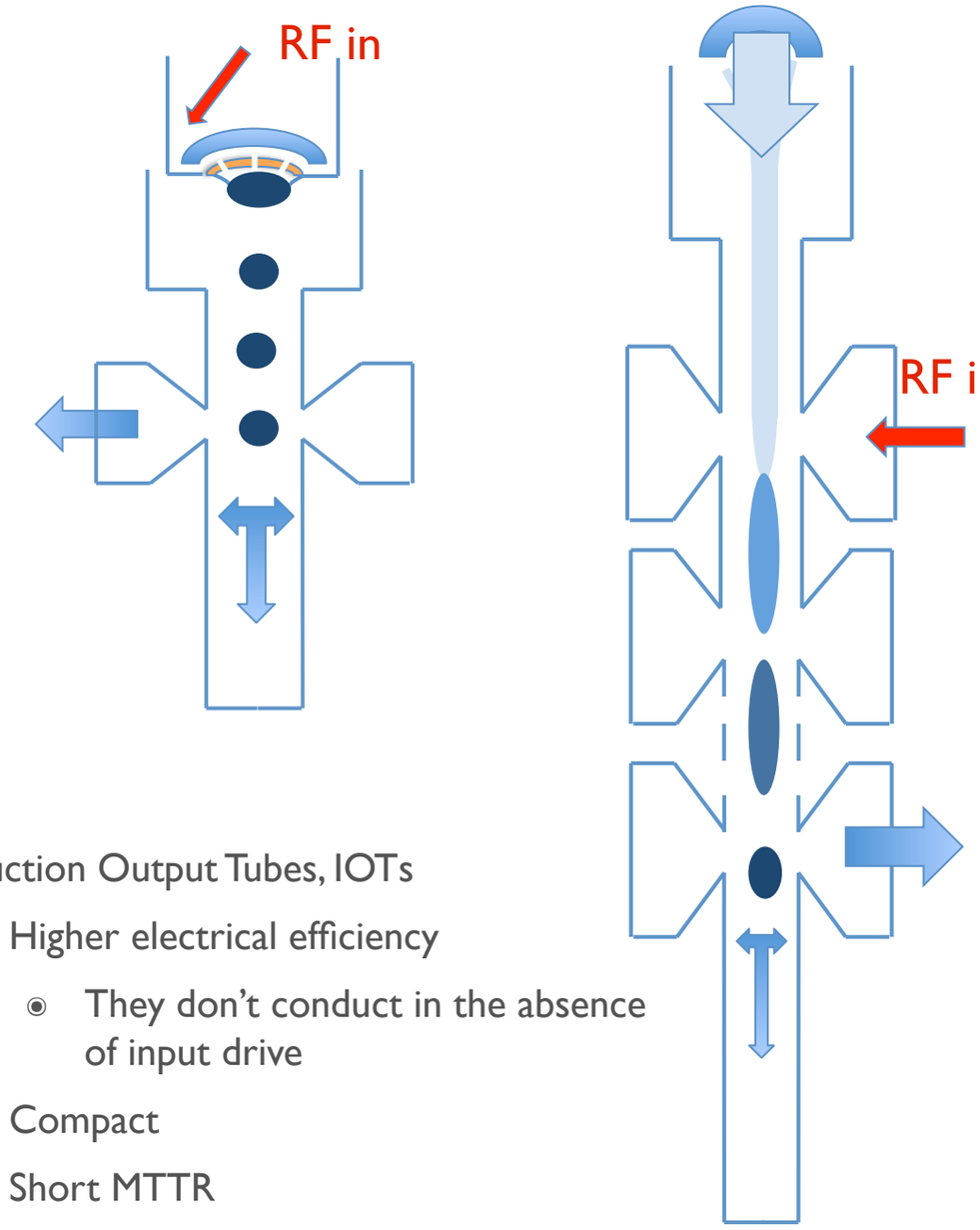


- The Resonant Multi-Level (RLM) topology for ESS modulators and HV power supplies
  - Flexible in adapting to different voltage/current requirements
  - Works in pulsed mode (Klystrons) and DC (IOTs)
  - Low voltage energy storage; good isolation and fast discharge in case of emergency

Courtesy: Carlos A. Martins

IOT
Density Modulation

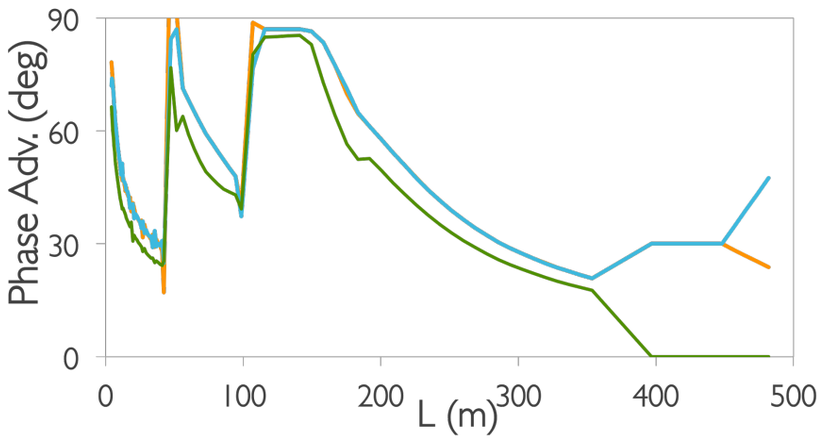
Klystron
Velocity Modulation

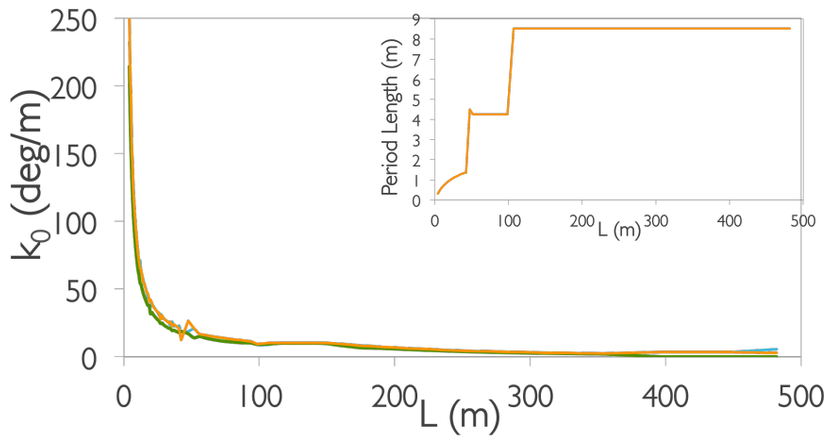


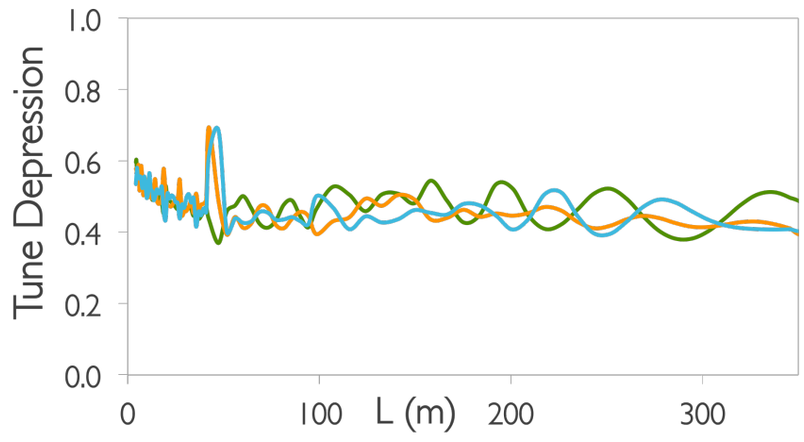
- Induction Output Tubes, IOTs
  - Higher electrical efficiency
    - They don't conduct in the absence of input drive
  - Compact
  - Short MTTR
  - Cheaper modulator (No high voltage switching)

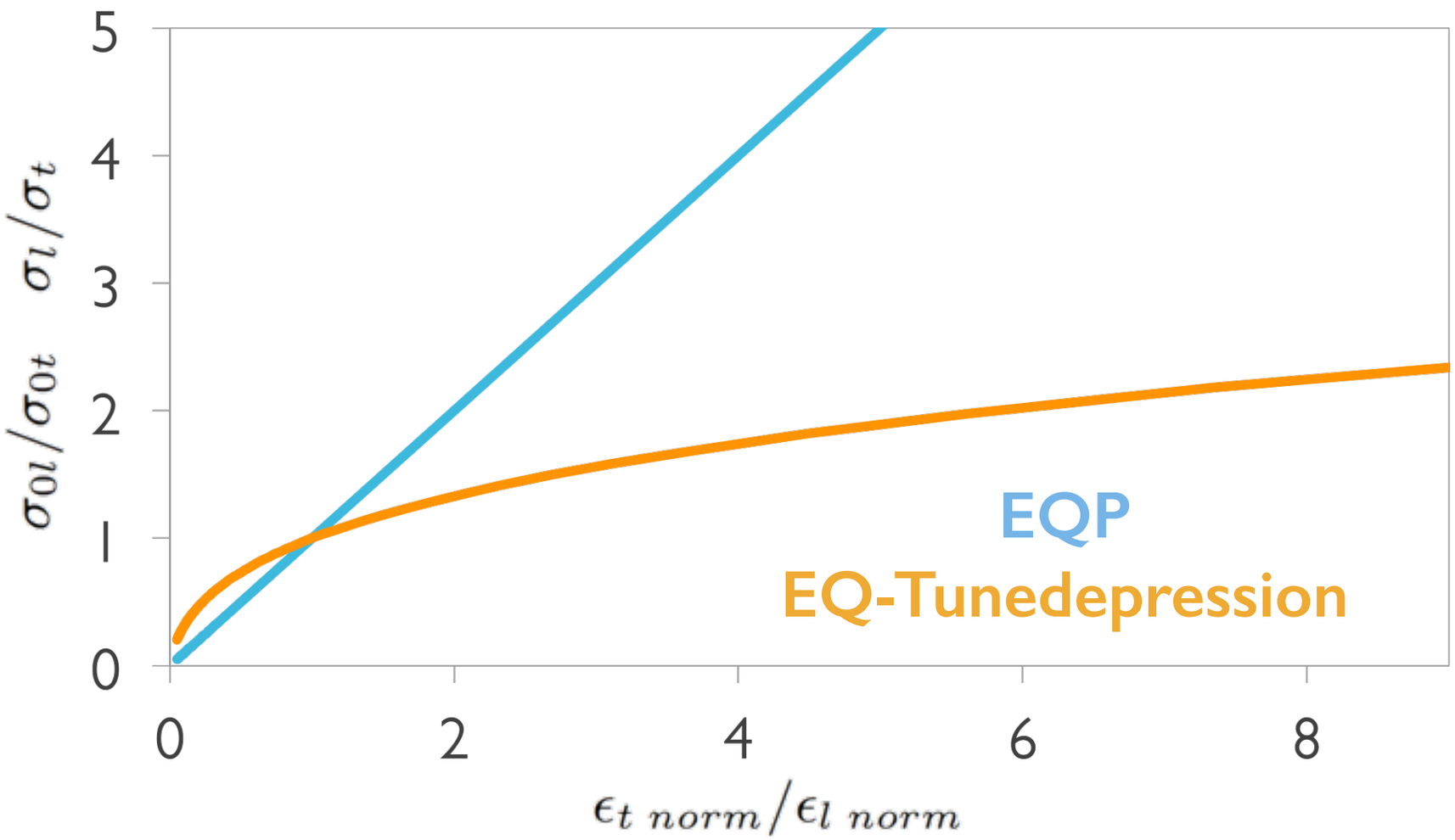
Courtesy: Morten Jensen

Beam physics and Halo

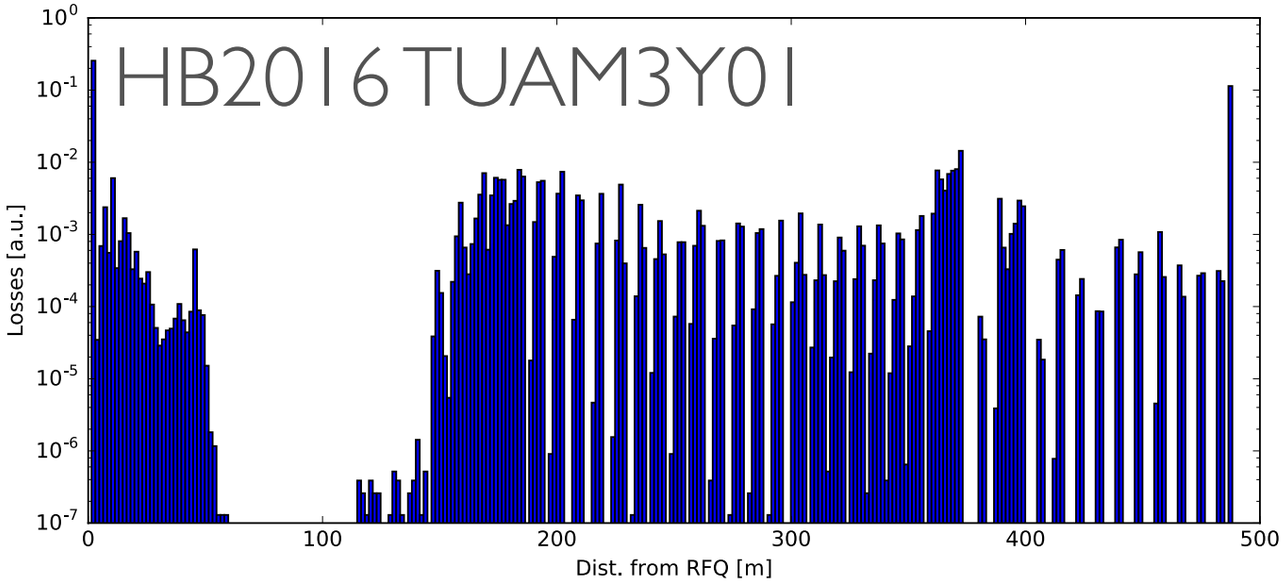


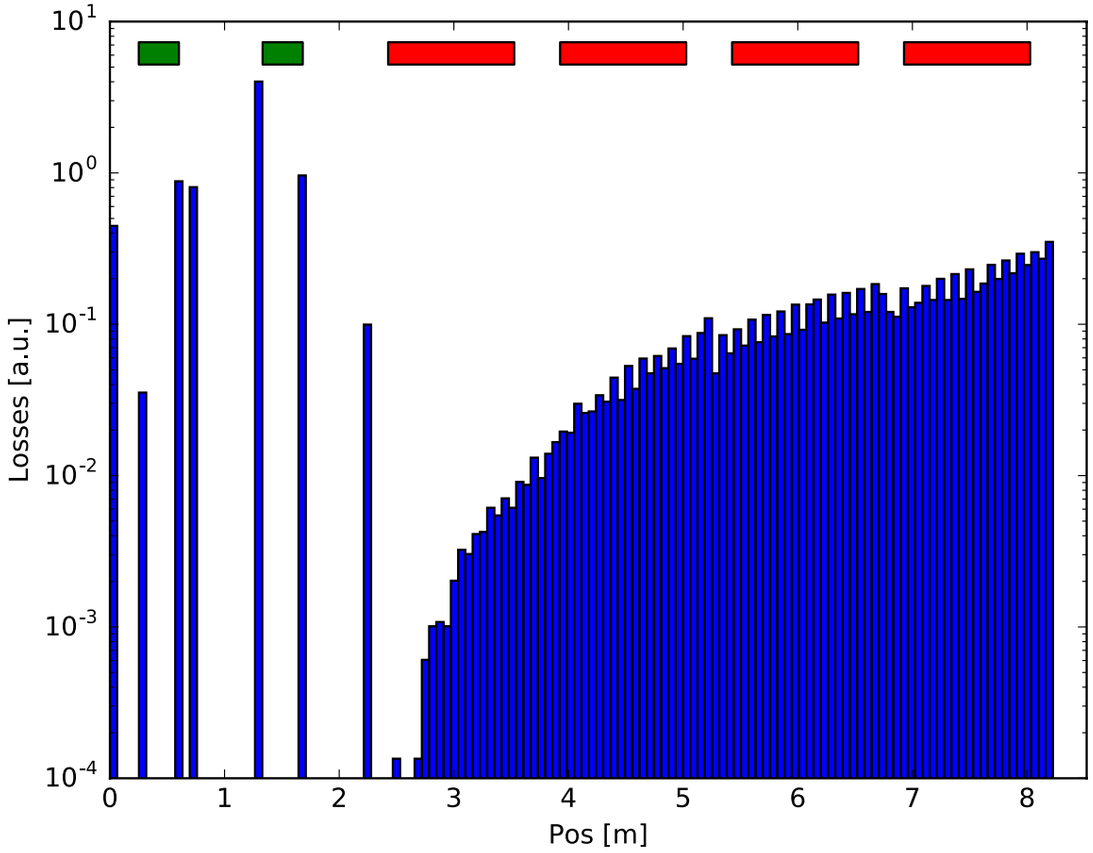




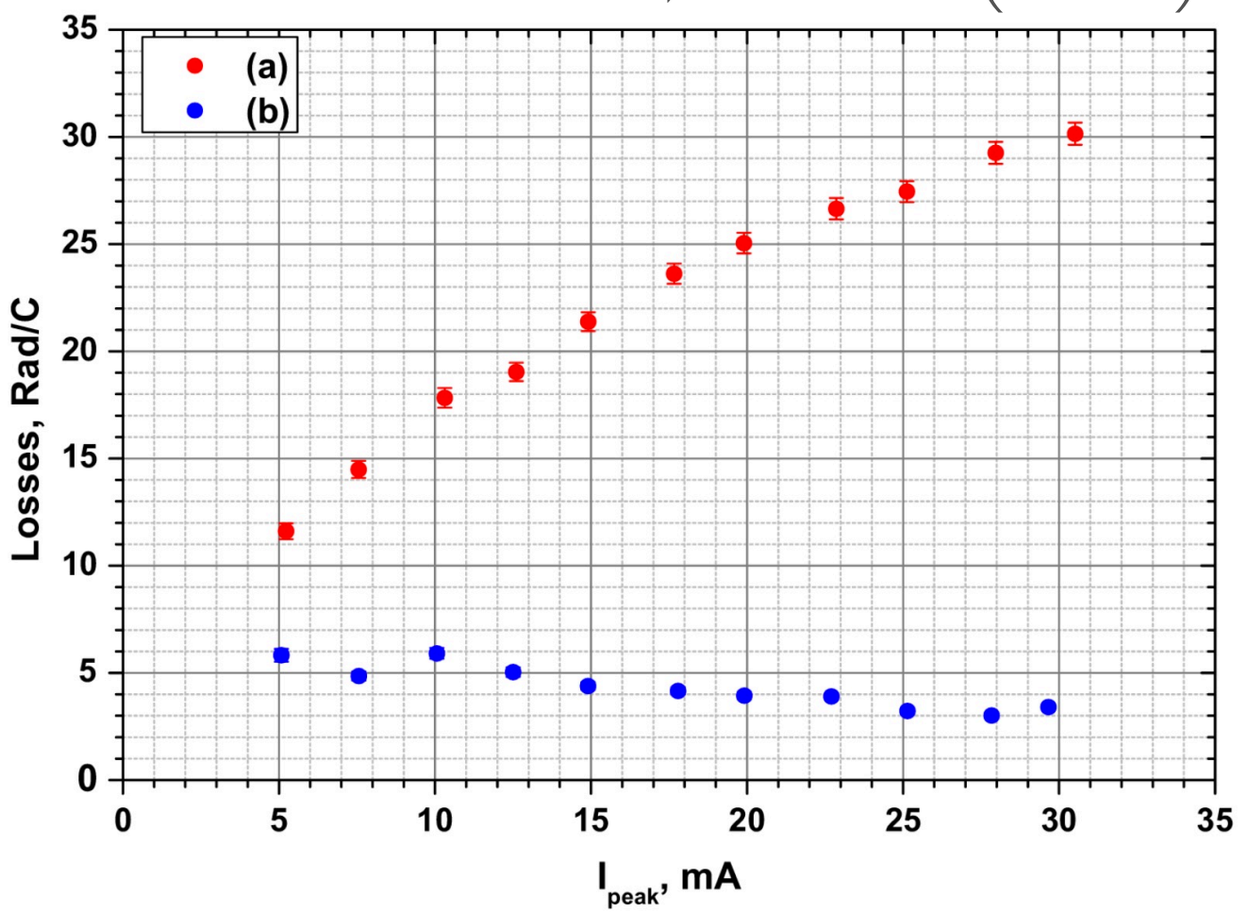


P Losses and H- Stripping

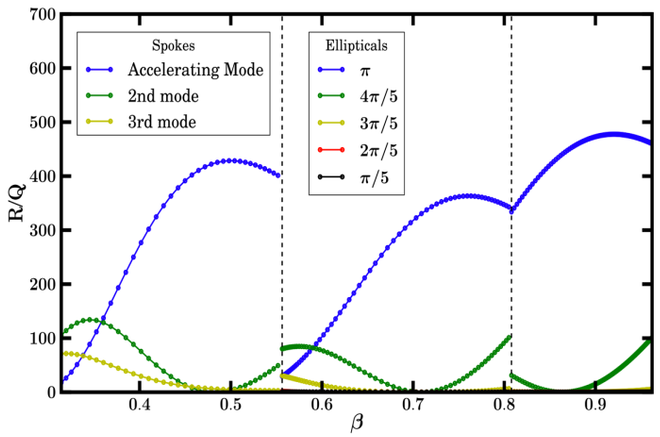


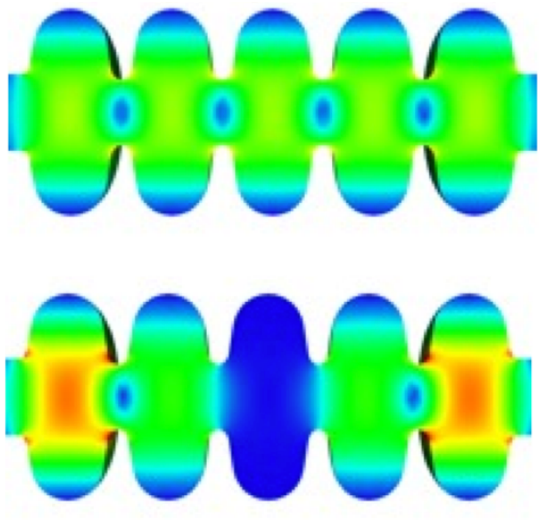


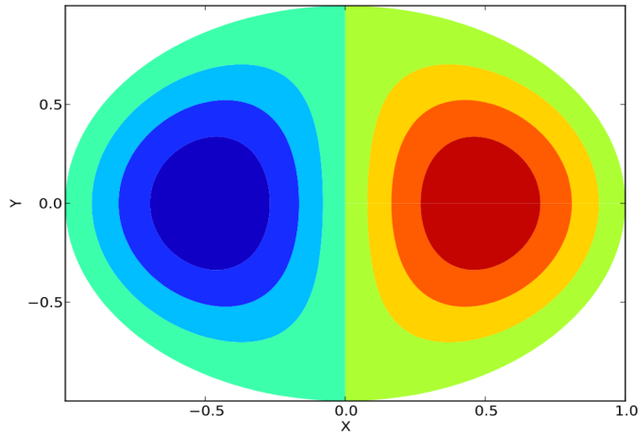
PRL **108**, 114801 (2012)

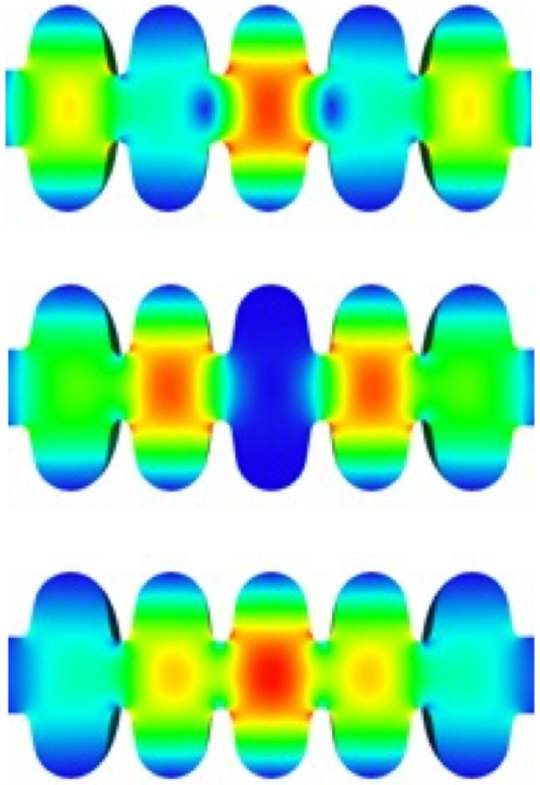


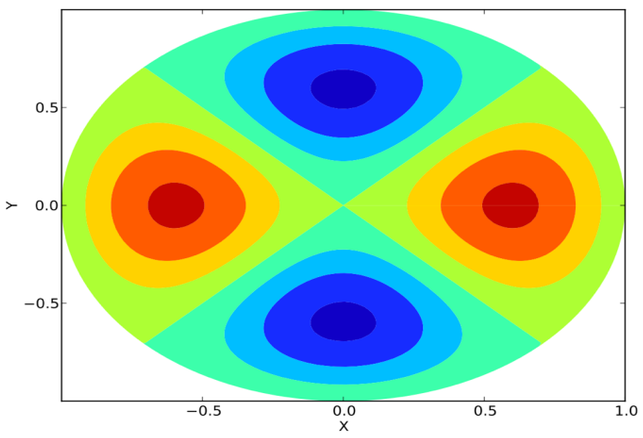
SOM AND HOMs


Spokes
Accelerating Mode
2nd mode
3rd mode
Ellipticals
π
4π/5
3π/5
2π/5
π/5
R/Q
β
0
100
200
300
400
500
600
700
0.4
0.5
0.6
0.7
0.8
0.9




Y
X
0.5
0.0
−0.5
−0.5
0.0
0.5
1.0




Y
X
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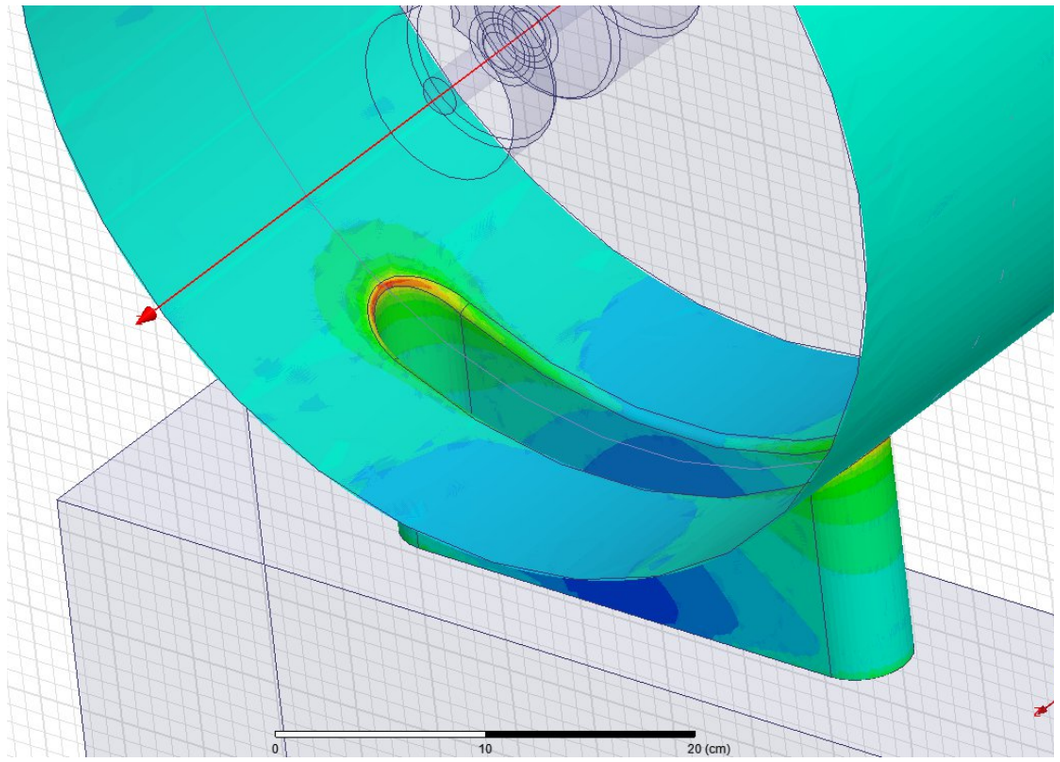
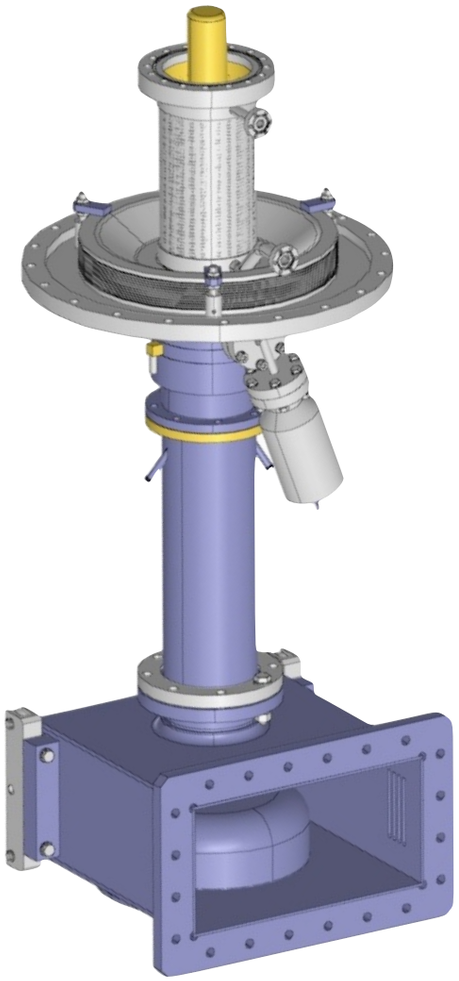
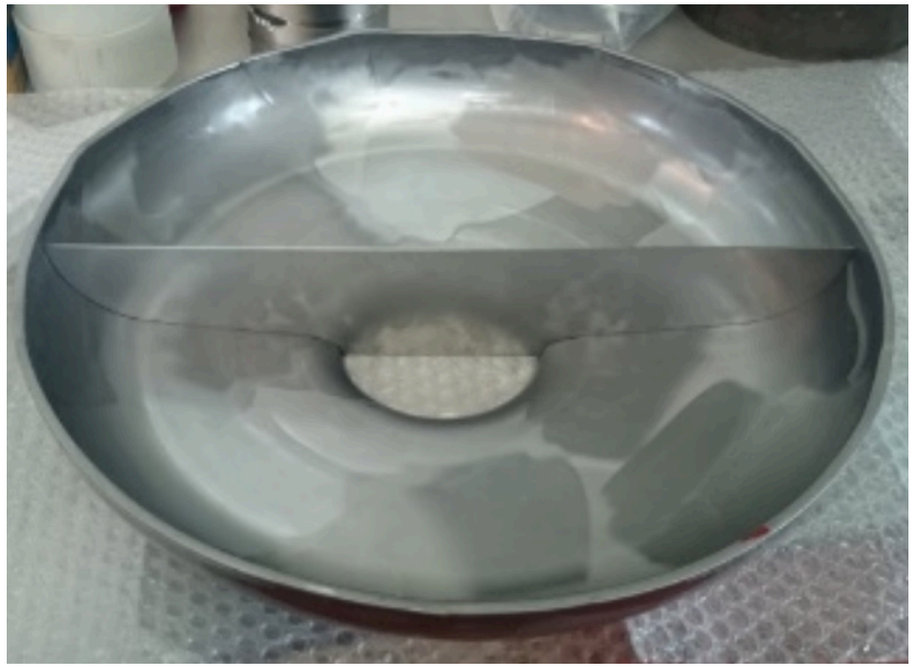
0.0
−0.5
−0.5
0.0
0.5
1.0

COUPLER





LARGE GRAIN SC CAVITIES



Courtesy: Paolo Michelato

SUMMARY

- Reducing the costs of the projects should be one of the objectives.

- Currently halo and losses are the biggest concerns of high power linacs.

- Methods to produce SC cavities more efficiently, e.g. large grain, hydro-forming will help future SC linacs

- In high intensity machines (with high chopping frequency) the HOMs are important and the development of HOM couplers should be pursued.
  - SOMs could be avoided to a large extent by proper selection of transition energies.

- Main couplers are limited to ~1 MW of power, future machines will need higher power capability.

Thank you

and

Best wishes for APEC