OVERVIEW OF HIGH INTENSITY LINAC PROGRAMS IN EUROPE

- Linacs as sources of secondary particles
- EU and accelerator research
- High Intensity Linac projects for ν, RIB, n
- Technical features
- The HIPPI Joint Research Activity

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Linacs as proton drivers

Renewed interest in high-intensity linear accelerators, driven by their use as sources of intense secondary beams:

- Neutrinos for Particle Physics.
- Radioactive Ion Beams (RIB) for Nuclear Physics.
- Neutrons for condensed matter studies or energy production/waste transmutation

Some reasons for this interest in linacs:

- Operate at high repetition rate/CW with limited current per bunch.
- Cost is going down thanks to progress in design and in Superconducting technology.
- Offer high flexibility (upgrades) and reliability.

Note: In the present overview only proton and H^- linacs for high average current (pulsed or CW)

EU driving accelerator research

2003/04: Call for projects in the 6^{th} Framework Program for Research and Technology of the European Union (2004-08)

→ (up to now) good success of accelerator projects.

EU vocabulary:

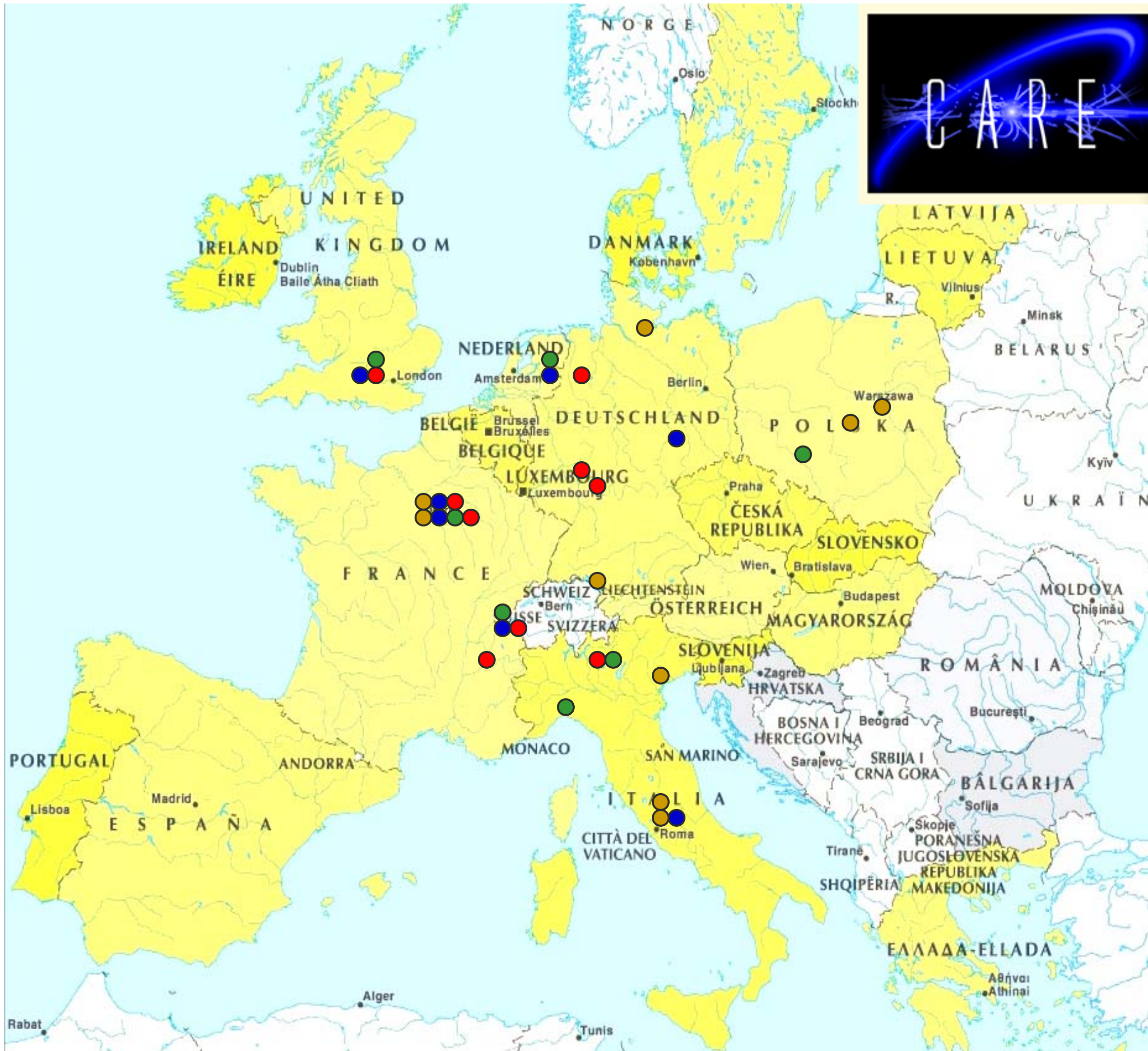
- I3= Integrated Infrastructure Initiative
- JRA=Joint Research Activity
- DS = Design Study
- IP = Integrated Project

= coordinated research programs for a given topic involving labs and universities from EU member states and associates.

Partners establish a common schedule and share resources to achieve the objectives. Selected projects can receive from EU up to 50% of the sum of individual contributions (typically, some 25% in case of successful projects).

EU selection is made on scientific case and on level of integration.

An example: the CARE Initiative



- JRA1, SC RF, 11 participants
- JRA2, Photoinjectors, 8
- JRA3, H.I. Linacs, 9
- JRA4, HF Dipole, 7

N1, e^+/e^- Colliders, 64

N2, Neutrino beams, 51

N3, Hadron beams, 28

Total of 110 participants scattered across Europe…

The EU: asset or burden ?

Clearly, an important effort in managing these large collaborations,

but is the EU contribution worth the effort?

Large amount of paperwork (monthly/quarterly/yearly reports, strict financial accounting for Brussels) and mandatory meetings, against a somehow limited contribution.

Many answers, but let's be positive:

> the real added value of working inside a EU project is not the money but the synergies between projects and the establishment of easy communication links.

(That is exactly the objective of Brussels…)

Particle Physics applications
of high-intensity linacs

Production of intense neutrino beams

Three sources of accelerator ν

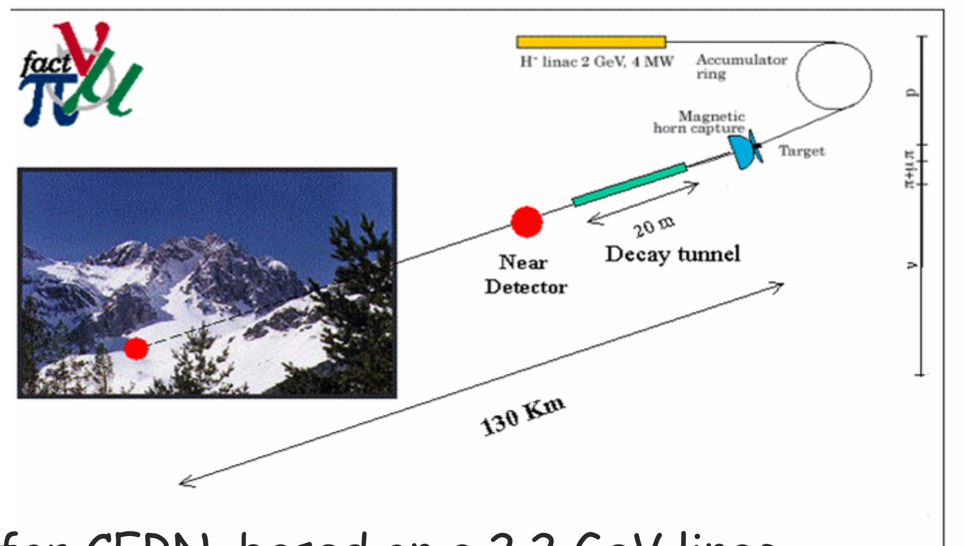
After discovery of neutrino masses, a strong support is growing for long baseline experiments with accelerators ν.

3 sources of accelerator ν's:

1. Conventional beam: π decay channel (=SuperBeam, if MW power)
2. Neutrino Factory: μ accelerator complex + storage ring
3. BetaBeam: RIB accelerator complex + storage ring

All 3 cases need a ~4 MW proton driver:

Competition between
* "low"-energy (linac+accumulator)
* high-energy (cascade of RCS's): comparable cost, but linac more flexible



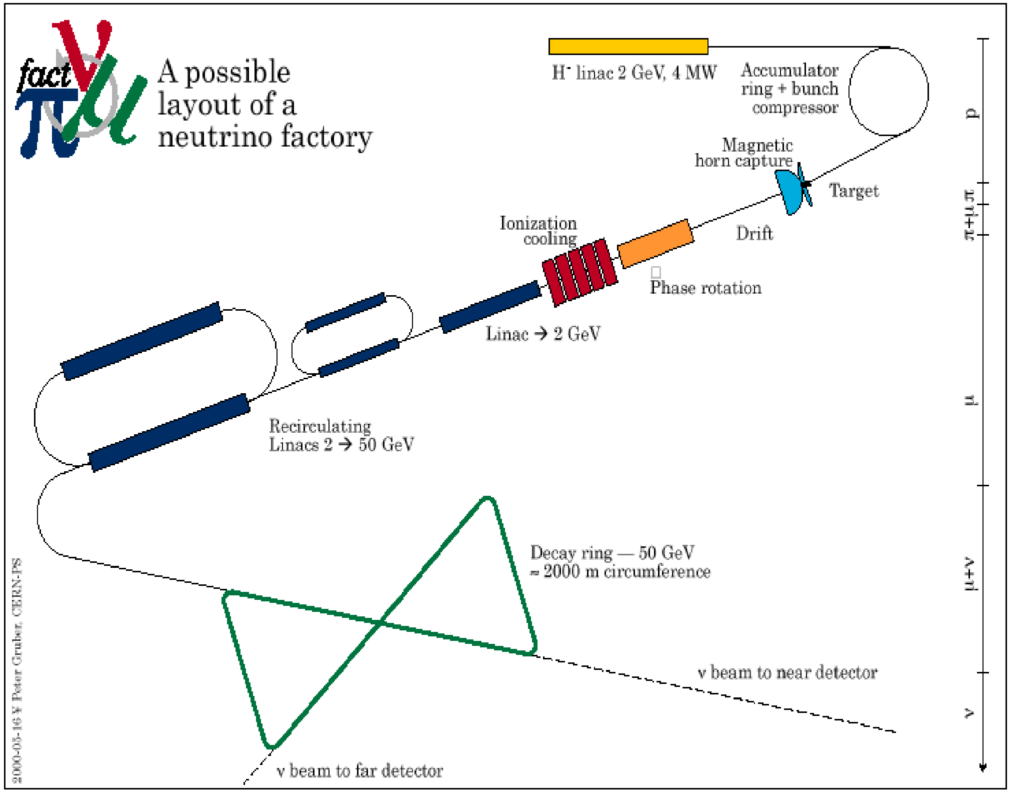
Example: the Superbeam concept for CERN, based on a 2.2 GeV linac

Accelerator, target and decay channel at CERN → project of a 400 kton detector in the Frejus tunnel under the Alps (130 km)

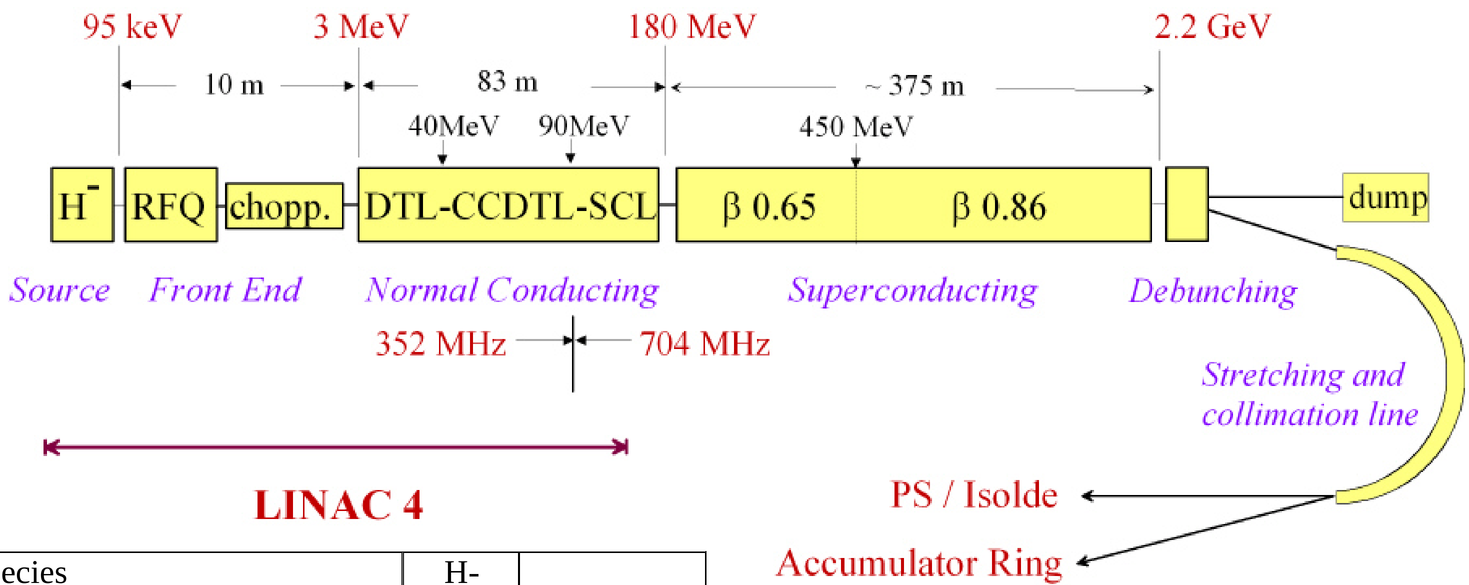
Neutrino Factory

Then, the same high intensity linac can be used as driver for a Neutrino Factory

Study done at CERN in 1999-2001, huge complex of accelerators producing 2 intense neutrino beams pointing towards near and far detectors.



The SPL design at CERN



Ion species	H-	
Kinetic energy	2.2	GeV
Mean current during the pulse	30	mA
Beam duty cycle	6	%
Mean beam power	4	MW
Pulse repetition rate	50	Hz
Beam pulse duration	1.2	ms
Bunch frequency	352.2	MHz
Duty cycle during the pulse	62	%
Normalized rms transv. emittances	0.4	πmm mrad
Longitudinal rms emittance	0.3	π deg MeV

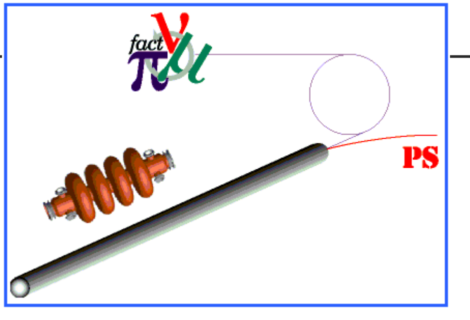
project originally intended to re-use the 352 MHz RF from LEP

Energy of 2.2 GeV:

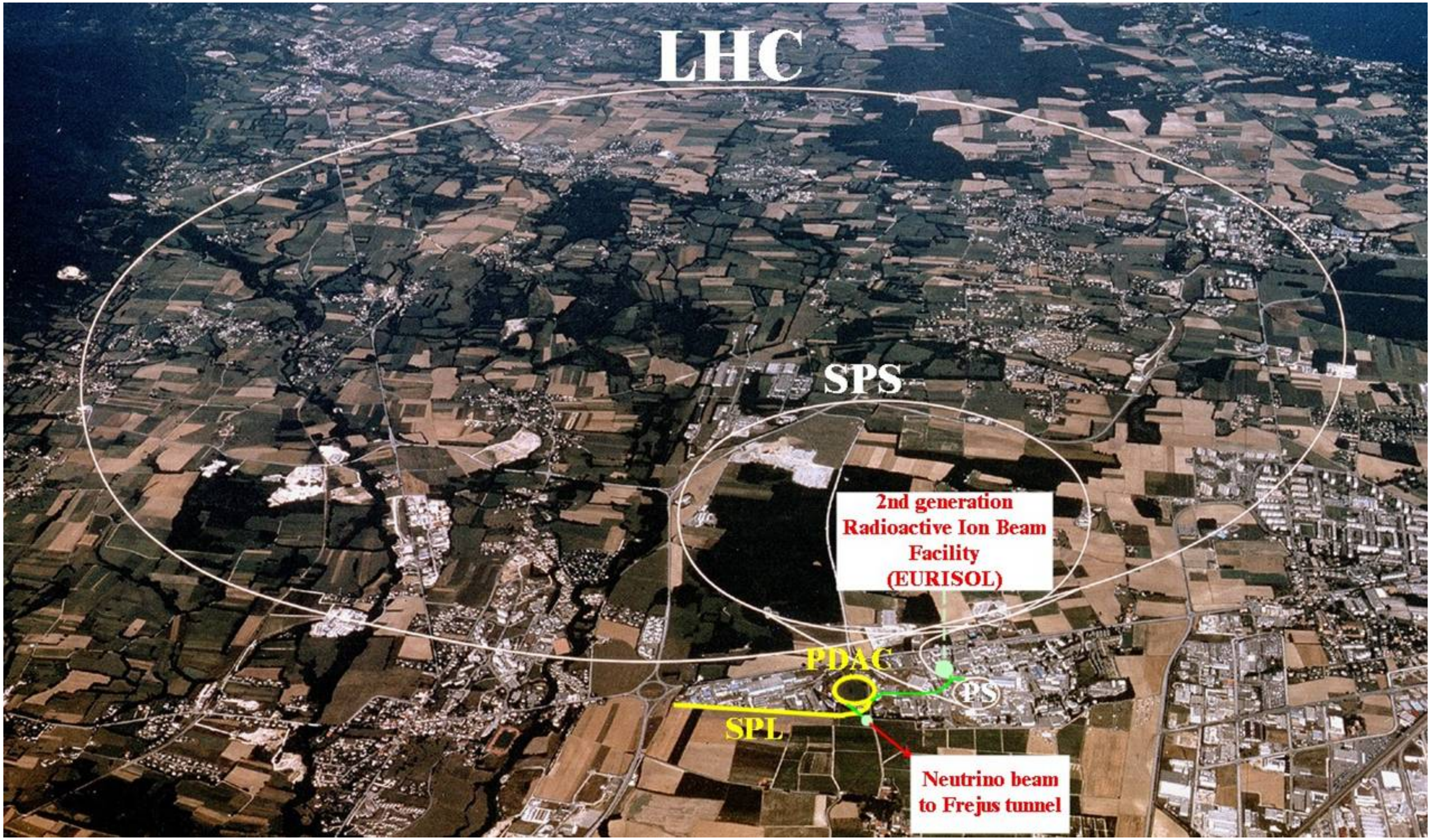
- above threshold for π production
- injection into PS at higher energy

New features of the SPL design

- design was originally based on the LEP cavities, but now their technology is aging and know-how is disappearing, while bulk Nb is supported by other laboratories and provides higher gradients,
  ⇒the SPL design is now based on 704 MHz bulk Nb resonators.
  No superconducting LEP cavities used anymore.
  Will be also studied an option at 1408 MHz SRF.
- The energy will be re-optimized as a function of physics goals (results of the HARP experiment on π production).
- Implementation strategy:
  a. in 2006-10, construction of the 160 MeV NC section (Linac4) (H^- into CERN Booster). R&D progressing and supported by EU, decision on construction foreseen for end 2006.
  b. In >2008 decision on the construction of SPL



SPL on the CERN site



Nuclear Physics applications
of high-intensity linacs

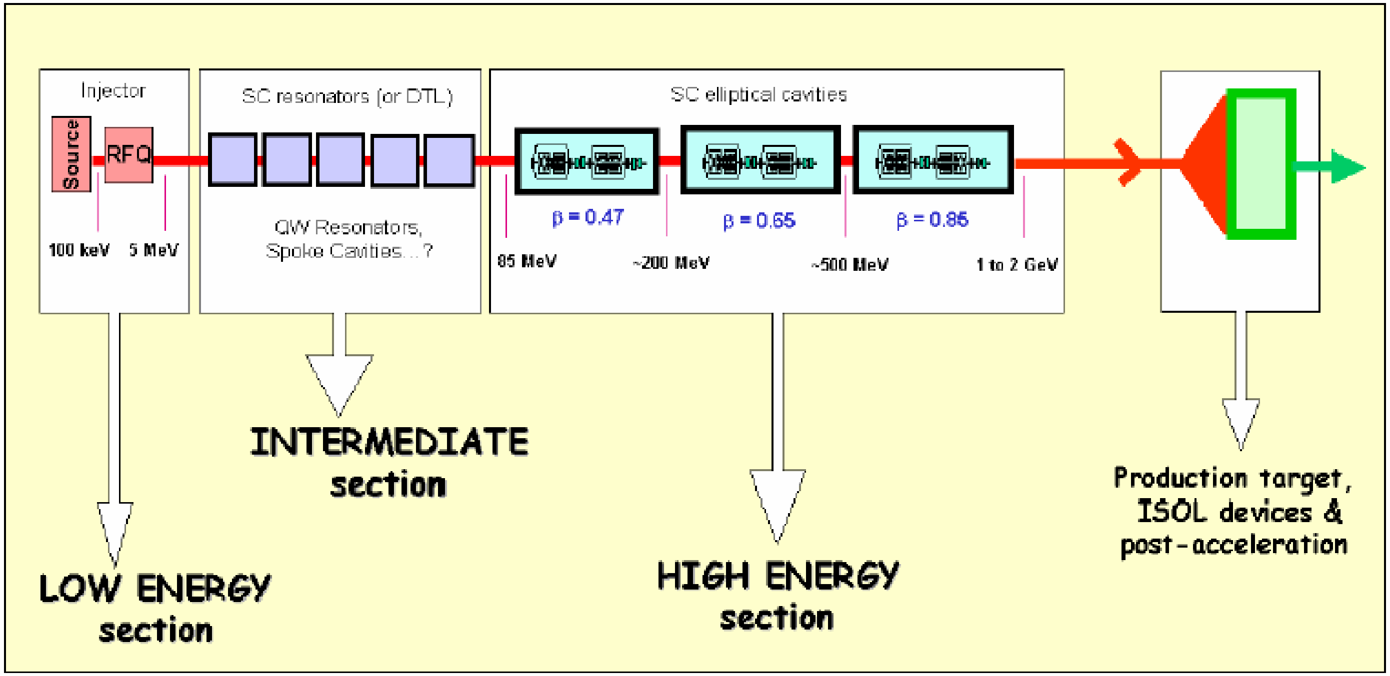
Production of intense
Radioactive Ion Beams

Nuclear Physics Applications

- Strong demand to establish in Europe a Radioactive Ion Beam (RIB) laboratory, with intensities 3 orders of magnitude higher than existing facilities, for nuclear physics and solid state physics, biophysics, nuclear astrophysics, etc.
- 2 parallel programmes: in-flight at GSI, ISOL in a new laboratory.
- Ideal driver:

  - high-intensity 1-2 GeV proton linac
  - operating in 2 modes: ~100 kW for ISOL target + few MW beam power for fission products from spallation
  - CW or pulsed at ≥50 Hz.

The EURISOL Design Study

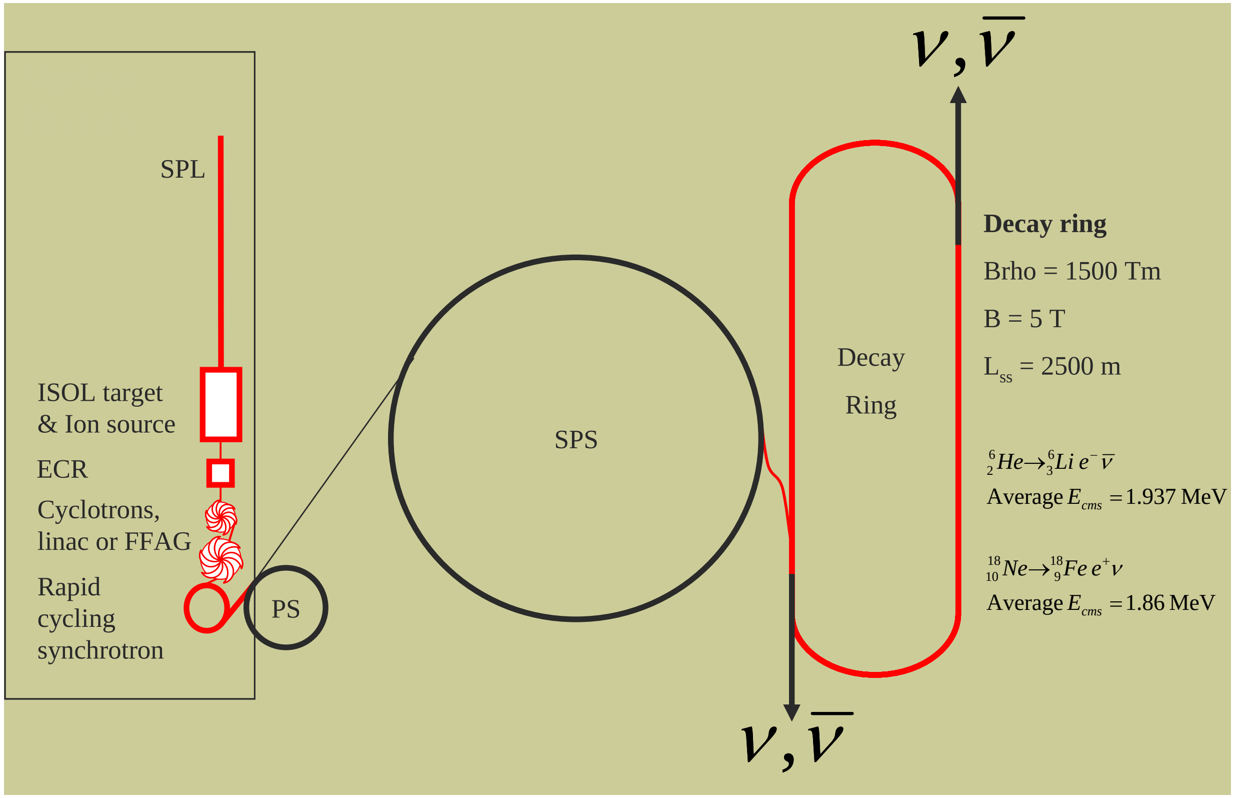


- Large collaboration present already in 5th FP of EU.
- Submitting a Design Study under 6th FP, positively evaluated by EU.
- CW, NC 5 MeV Front-end, 352 MHz SC Intermediate, 704 MHz SC
- Individual resonators for protons + low mass ions

EURISOL at CERN and the beta beams

EURISOL at CERN using the SPL would provide a chance to combine a nuclear facility and a neutrino facility in a beta-beam facility

Novel idea (by P. Zucchelli), analyzed now inside the EURISOL study.



RIB facility → production of large quantities of beta-emitting ions → accelerated in post-accelerator + CERN accelerators → decay ring → 2 intense streams of neutrinos.

Neutron production applications

of high-intensity linacs

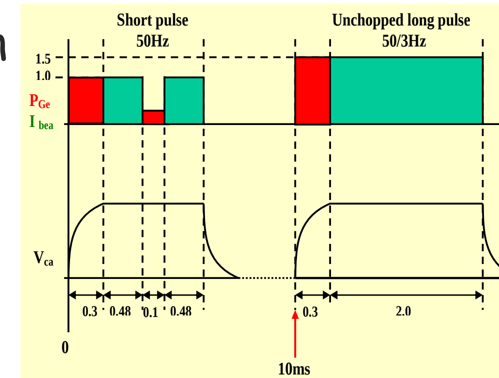
Production of intense fluxes of neutrons for

-basic science and condensed matter studies

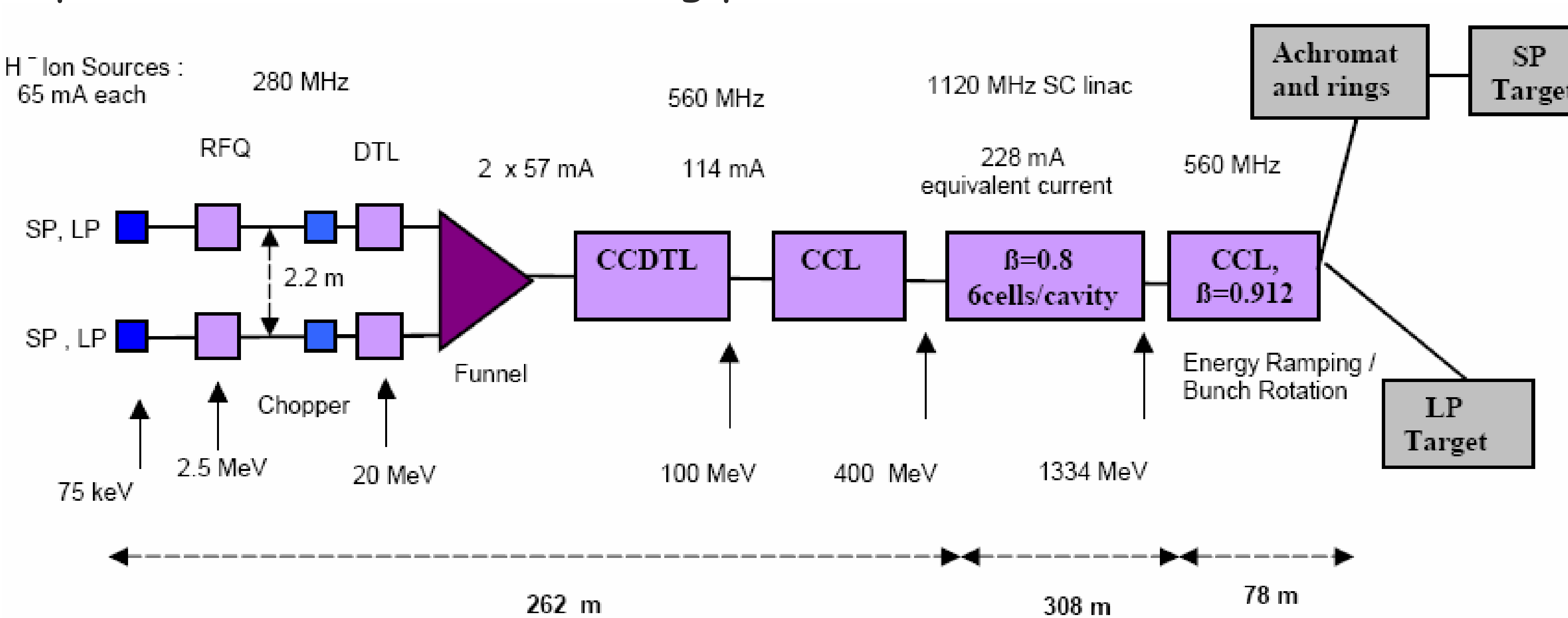
-feeding sub-critical reactors

European Spallation Source

Not considered in 2003 review, will be submitted again in 4-5 years. Refinement of technological layout, with 2 new features:



- 1120 MHz SC section from 400 MeV
- novel chopper/collector, required for the dual operation mode (short and long pulse, 5 MW each)



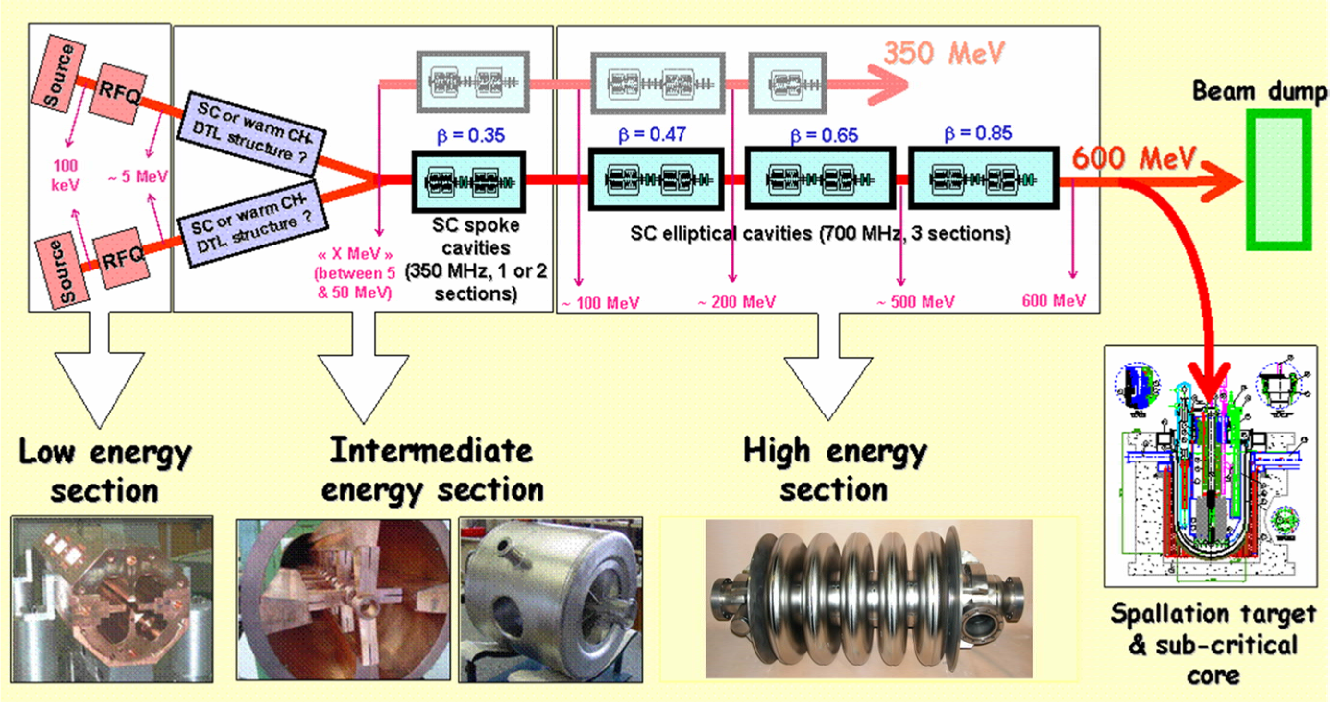
XADS

Accelerator group in the EU ADS Study has investigated the characteristics of transmutation driver for 600 MeV, 6 mA, <5 trips/year.

Conclusions: CW SC linacs preferred to cyclotrons (reliability, upgradeability).

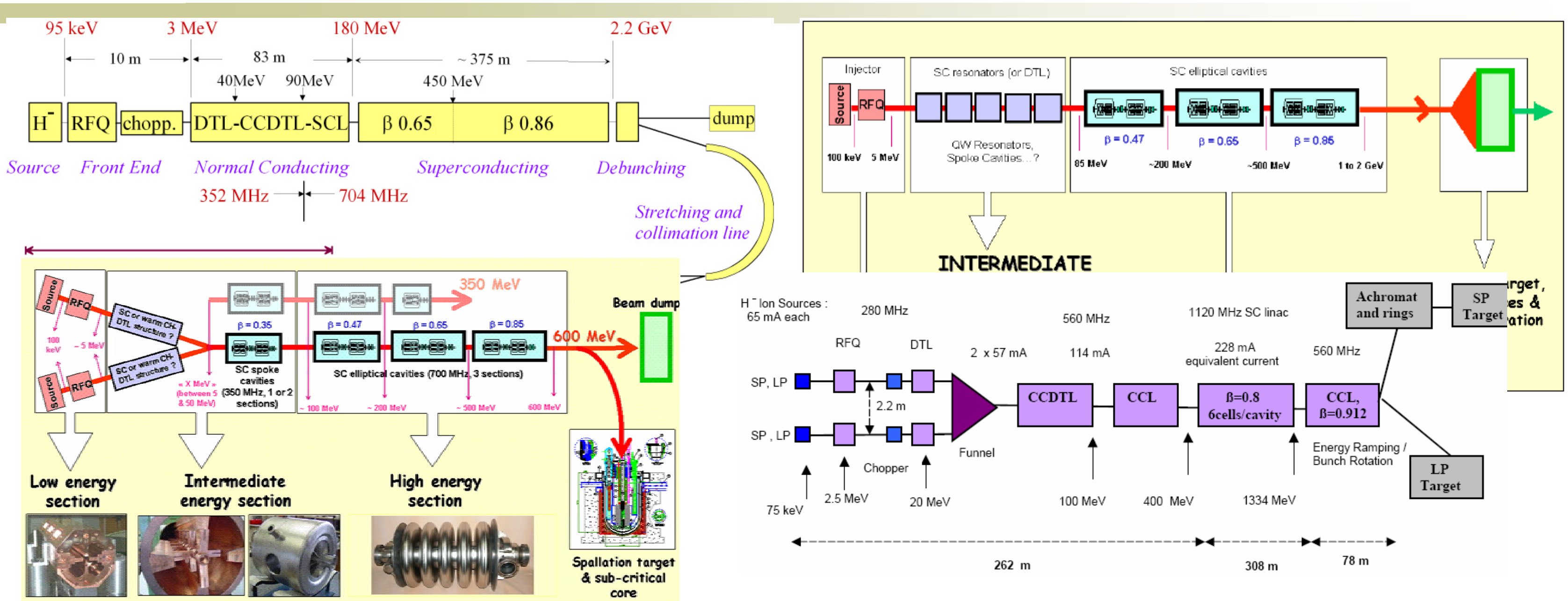
Reference layout: double front-end, SC from few MeV, CH structure.

Integrated Project EUROTRANS now submitted to EU, reliability + demonstrators. Seek funding for construction in next FP (2008)



Technological issues

Some common features



Many similarities in the designs (the teams are often the same) and common work, encouraged by EU. Details are tailored to the application. Some common features:

1. European frequency choice: 352 MHz & harmonics (←LEP).
2. All Superconducting (>5 MeV for CW, 180-400 MeV for pulsed)
3. All aim for a decision on construction ~2008/10

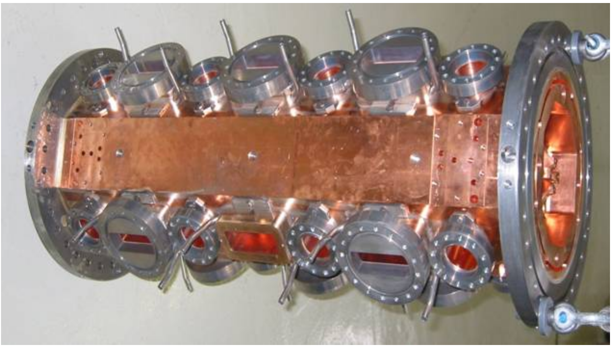
Open issues

1. The Front-end: generation of the particle distribution +

   many technological challenges (high duty RFQ, chopper, etc.)
2. Superconducting linac: cavity development, vibration compensation
3. Medium energy linac: NC/SC structure selection
4. Beam dynamics: halo generation and collimation

Front-ends

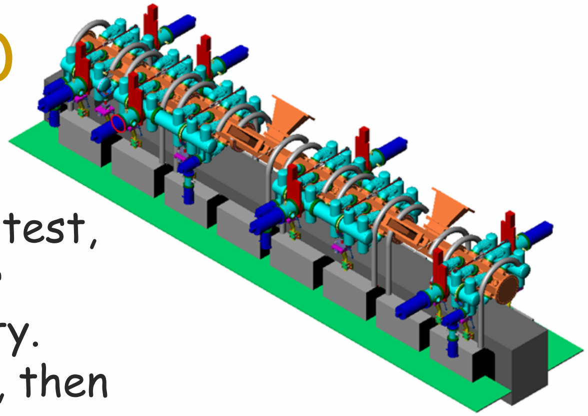
2 high-intensity RFQ's under construction in Europe:

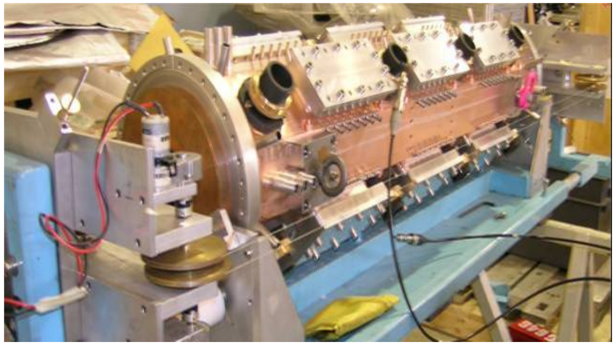


IPHI RFQ (CEA-IN2P3)

100mA, CW, 3 MeV

designed for transmutation test, will become the injector for CERN Linac4/SPL at low duty. CW tests at Saclay in 2006, then at CERN from 2007

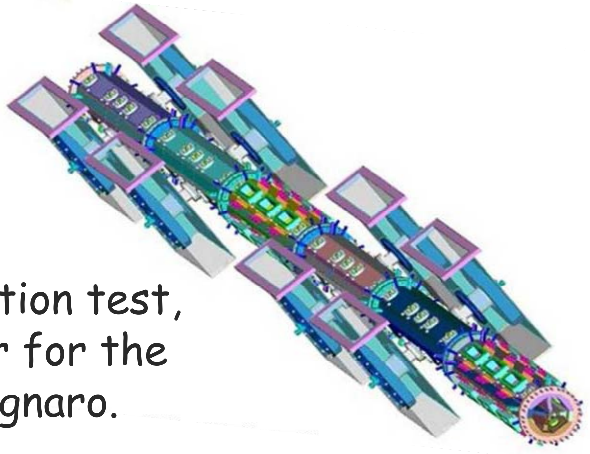




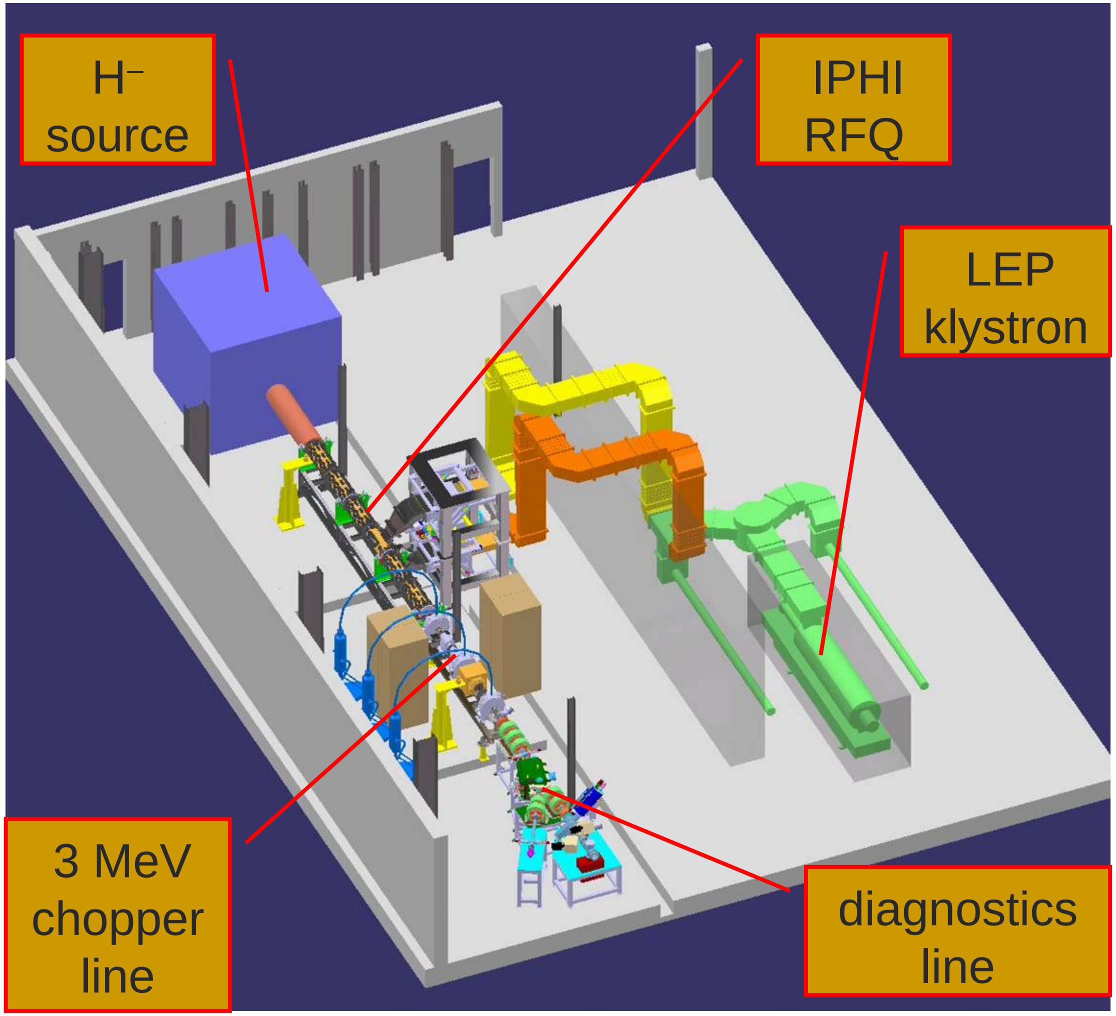
TRASCO/SPES RFQ (INFN-LNL)

30mA, CW, 5 MeV

designed for transmutation test, will become the injector for the SPES RIB facility at Legnaro. Tests in 2008 at LNL



The 3 MeV test stand at CERN



Under construction, operational in 2007.

IPHI RFQ + H⁻ source + chopper line at 3 MeV + diagnostics line (incl. halo measurements)

The beam distribution is generated in the front-end:

source extraction, RFQ multipoles, changes of beam size and focusing period in LEBT and MEBT determine the halo that will influences losses in the rest of linac

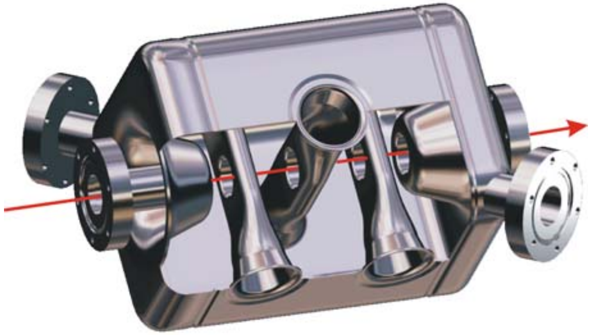
Early understanding and optimisation of front-end is fundamental for a high-intensity project.

Challenges of SC Linac

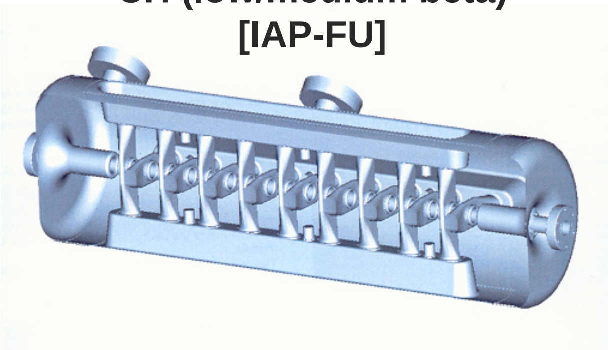
1. Choice of low-medium energy structures & transition NC-SC
2. Instabilities due to vibrations in pulsed mode. Consider piezos and high power ferrite modulators for feeding more cavities from one power source.
3. Go to even higher frequencies (1120 MHz for ESS, 1408 MHz option for SPL): advantages for gradient, smaller cavity size, reduced cooling power, large bandwidth but beam dynamics require an additional frequency jump (increased bunch current, phase spread, matching…). Possible synergies with TESLA !

Superconducting zoology

Spoke (low beta)
[FZJ, Orsay]

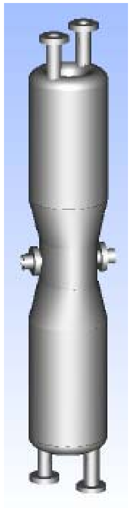


CH (low/medium beta)
[IAP-FU]



Multi-cell elliptical (medium/high beta)
[CEA, INFN]

HWR (low beta)
[FZJ, LNL, Orsay]



Re-entrant
[LNL]

QWR (low beta)
[LNL, etc.]

Medium energy linac - HIPPI

Inside CARE (EU project),

Joint Research Activity on *High Intensity Pulsed Proton Injectors*

Goal: in 2004/08, common work on linac R&D for the energy range 3-200 MeV, to prepare the technological basis for 3 linac projects:

- the new GSI proton injector
- the CERN Linac4
- the RAL linac upgrade

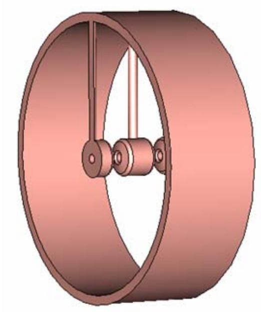
Partners: RAL, CEA-Saclay, CERN, FZ-Jülich, GSI, IAP-Frankfurt, INFN-Milano, IPN-Orsay, LPSC-Grenoble.

Development and testing of different prototypes, common beam measurements, final common assessments.

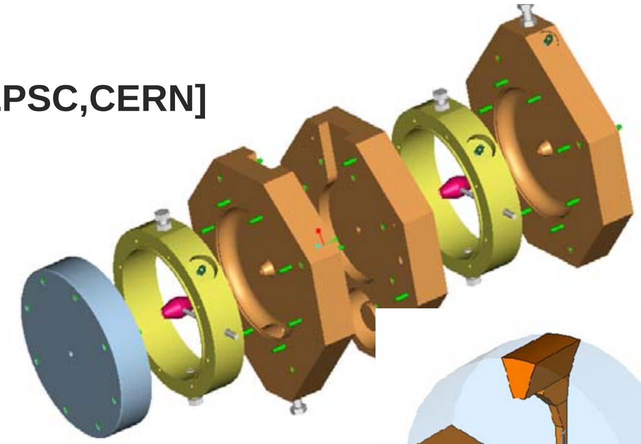
WP2 – Normal Conducting Structures

- Development of cold models and some prototypes of NC RF structures for acceleration up to an energy of ~ 100 MeV,
- Prepare comparative assessment with respect to SC solutions

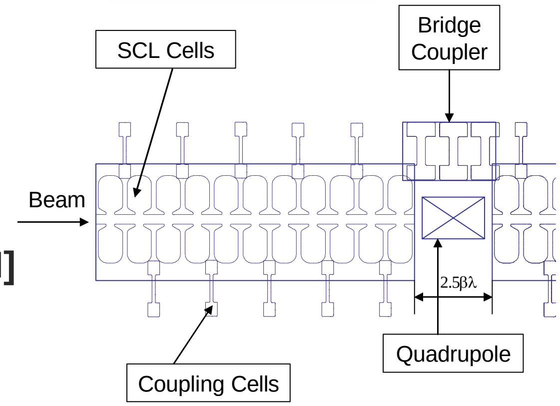
DTL Alvarez
[CEA, LPSC,CERN]



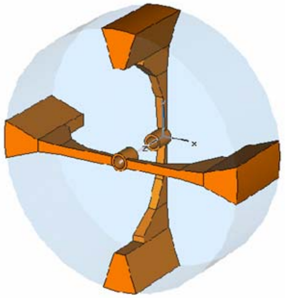
CCDTL
[CEA, LPSC,CERN]



SCL
[LPSC,CERN]



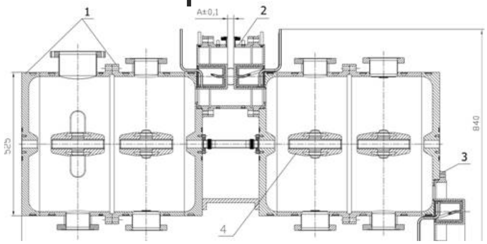
CH
[IAP-FU]



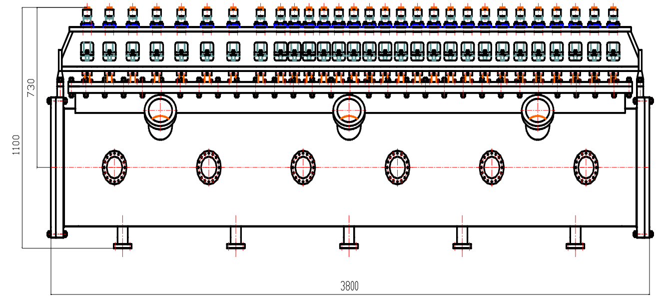
<u>Objective</u>: comparative assessment in terms of shunt impedance (goal : ZT^2 > 40 MΩ/m) and cost, in the energy range 3-100 MeV

The ISTC Collaborations

Integrated into HIPPI, 3 collaborations between CERN and Russian labs funded by ISTC, for the development of NC structures prototypes in 2004-05, to be tested with RF power at CERN



- Development of a 352 MHz 40 MeV CCDTL prototype + an SCL technological model (BINP Novosibirsk + VNIITF Snezinsk).



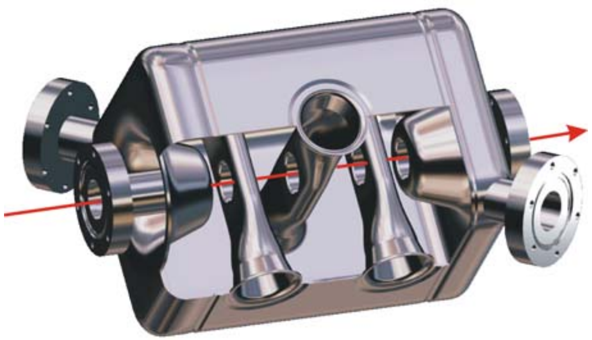
- Development of a 3-10 MeV DTL tank prototype with PMQ's (ITEP Moscow + VNIIEF Sarov).
- Development of a 3-15 MeV DTL-RFQ tank prototype (IHEP Protvino + VNIIEF Sarov).

Final goal of the 3 projects is to prepare for serial production in the Russian nuclear laboratories

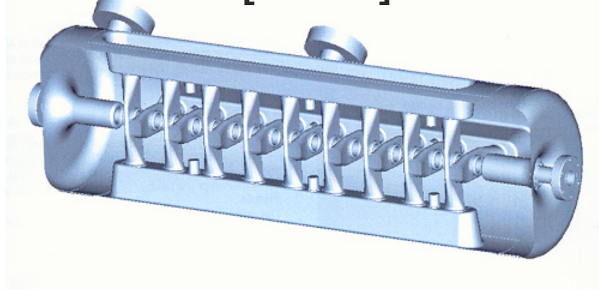
WP3 – Superconducting structures

- Characterization of SC RF structures for use in a pulsed linac.
- Investigation of different type of structures; prepare for comparative assessment
- Realization of a high power 704 MHz RF test place with cryogenic infrastructure

Spoke (low beta)
[FZJ, Orsay]



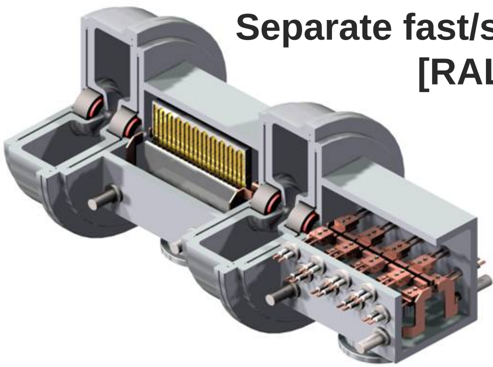
CH (low/medium beta)
[IAP-FU]



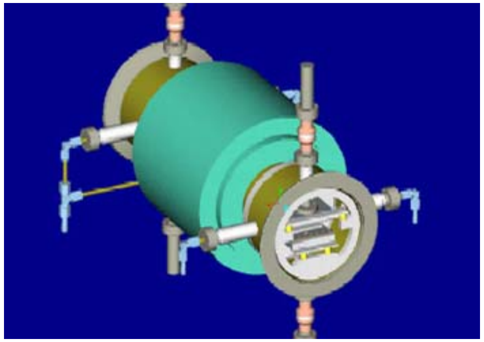
<u>Objectives</u>: gradient > 7 MV/m with Q > 10^{10} in the energy range 100-200 MeV, at a construction cost comparable to normal-conducting structures; development of efficient superconducting structures down to beam energies around 5 MeV; availability of a 704 MHz high power RF test place for SC cavities.

WP4&5 Chopping and Beam Dynamics

- Design chopping line, including choppers, driver sand dump.
- Build and test prototypes (with beam in the case of CERN).
- Compare solutions



Separate fast/slow kickers [RAL]



Broad band kickers [CERN]

<u>Objectives</u>: switching time smaller than the distance between bunches at 352 MHz (about 2 ns); chopper-line design minimizing emittance growth.

- Benchmark of simulation codes
- Develop special beam instrumentation to characterize halo and emittance blow-up
- Design collimation devices

<u>Objectives</u>:

• validate experimentally the simulation codes (using UNILAC @ GSI and 3 MeV @ CERN)
• define procedure for designing with uncontrolled beam loss below 1W/m

Few concluding remarks

- Projects based on high-intensity linacs are showing more integration at the European level, well considered at Brussels.
- The European Projects that are now starting represent a formidable scientific and human challenge.
- Technology is progressing, more test stands are tacking off and more partners are joining linac R&D.
- After a 5 years R&D period 4 European projects expect a decision on construction…