CARE

APD

Accelerator Physics and synchrotron Design

CERN

SPL session summary

- Talks & speakers
- Plans for proton linacs at CERN
- Lessons on superconducting proton linacs
- Synergies with other projects

R. Garoby
5/10/2007

Talks and speakers

Thursday 04 October 2007 9h00 – 12h30

	CERN plans	Lessons on sc linacs	Synergies with other projects
Linac-4 *Maurizio Vretenar (CERN)*	X		
Low Power SPL *Frank Gerigk (CERN)*	X		
SNS experience with a high-energy superconducting proton linac *John Galambos (ORNL)*		X	X
ESS plans and synergies with CERN *Klaus Bongardt (FZ Juelich)*			X
Development for laser-based H-stripping at SNS *John Galambos (ORNL)*			X
Reliability of a s.c. linac from the ADS perspective *Paolo Pierini (INFN Milano)*		X	X

Plans for proton linacs at CERN

Motivation

upgrade of the LHC proton injector chain:

- remove reliability concerns in the chain,
- provide a beam suitable for all foreseen LHC upgrade scenarios,

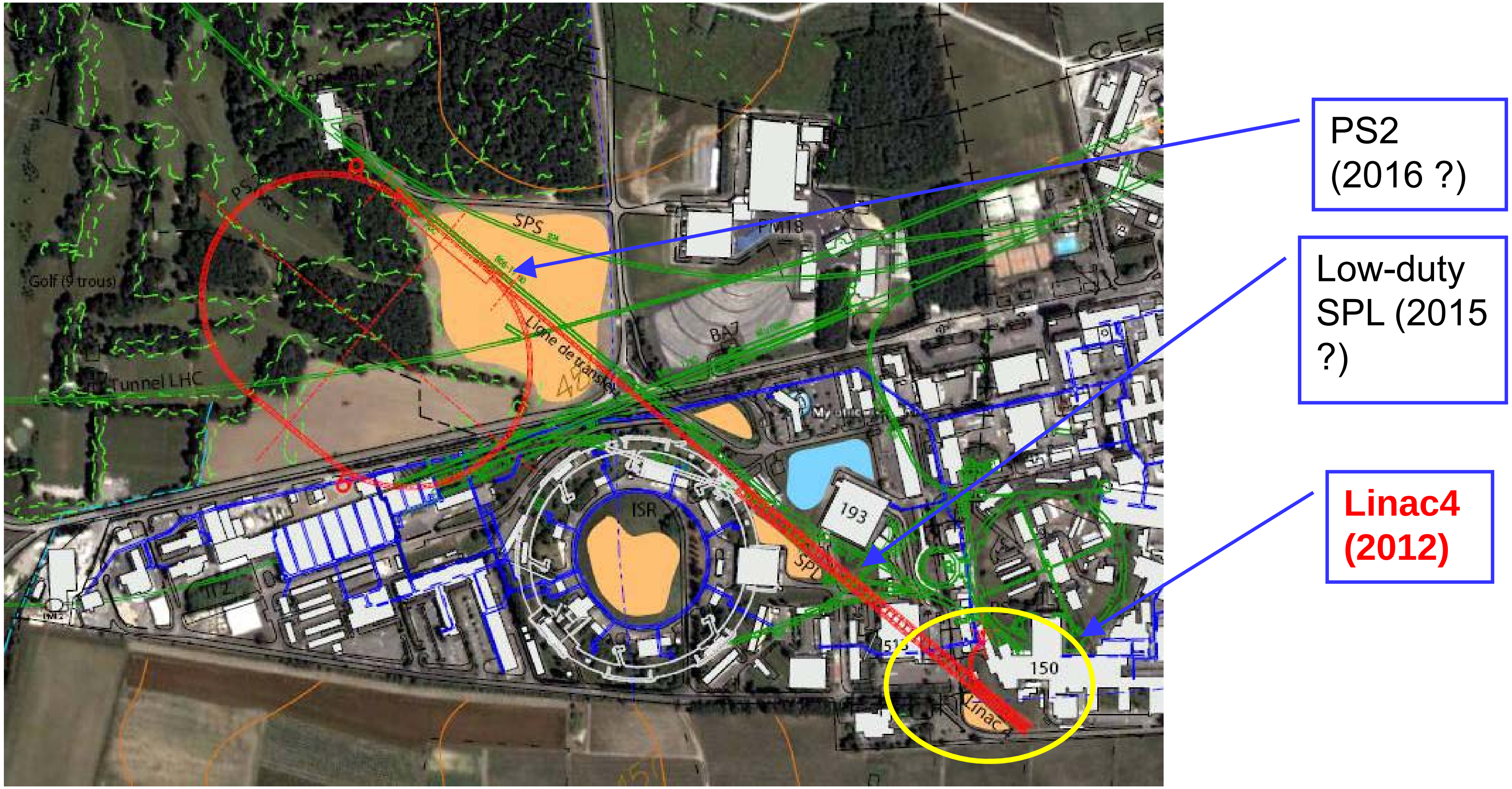
provide an injector that can be upgraded to supply protons for:

- neutrino physics,
- Eurisol/ISOLDE upgrades,
- performance improvement for SPS fixed target physics,

➡ see R. Garoby (Tuesday, 9:00 this workshop)

From F. Gerigk (CERN)

Linac4 and the new injectors



1st stage: Linac4 injects into the old PSB → increased brightness for LHC, more beam to ISOLDE, increased reliability.

2nd stage: Linac4 into SPL (and PS2) → renewed and improved LHC injection chain.

From M. Vretenar (CERN)

Linac4 parameters

Ion species	H−	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Beam Pulse Length	400	µs
Max. Beam Duty Cycle	0.08	%
Chopper Beam-on Factor	62	%
Chopping scheme:	222 transmitted /133 empty buckets	
Source current	80	mA
RFQ output current	70	mA
Linac pulse current	40	mA
N. particles per pulse	1.0	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad

Max. rep. rate for accelerating structures 50 Hz

H- particles + higher injection energy (160/50 MeV, factor 2 in $\beta\gamma^2$) → more accumulated particles in the PSB.

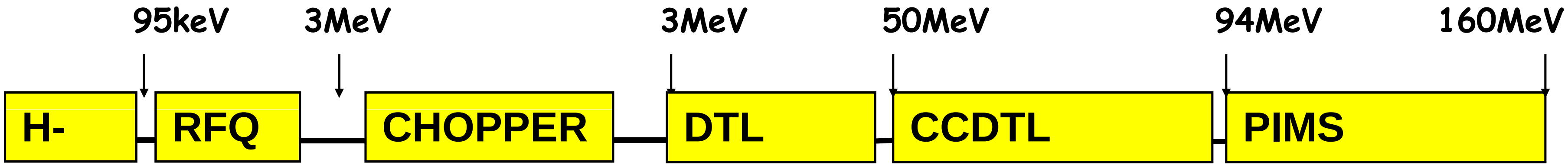
Will re-use 352 MHz LEP RF components: klystrons, waveguides, circulators.

2 operating modes: low duty for LHC, high duty for high-power SPL (neutrino or RIB physics) at a later stage.

- Structures and klystrons dimensioned for 50 Hz
- Power supplies and electronics dimensioned for 2 Hz.

From M. Vretenar (CERN)

Linac4 Layout



RF
volume
source
(DESY)
35 kV
Extrac.
+60kV
Postacc.

Radio
Frequency
Quadrupole
(IPHI)
352 MHz
6 m
1 Klystron
1 MW

Chopper

352 MHz
3.6 m
11 EMquad
3 cavities

Drift Tube
Linac

352 MHz
18.7 m
3 tanks
3 klystrons
4 MW
111 PMQs

Cell-Coupled
Drift Tube
Linac
352 MHz
25 m
21 tanks
7 klystrons
6.5 MW
21 EMQuads

Pi-Mode
Structure

352 MHz
22 m
12 tanks
8 klystrons
~12 MW
12 EMQuads

Total Linac4:
80 m,
18 klystrons

RF Duty cycle:
0.1% phase 1 (Linac4)
3-4% phase 2 (SPL)
(design: 10%)

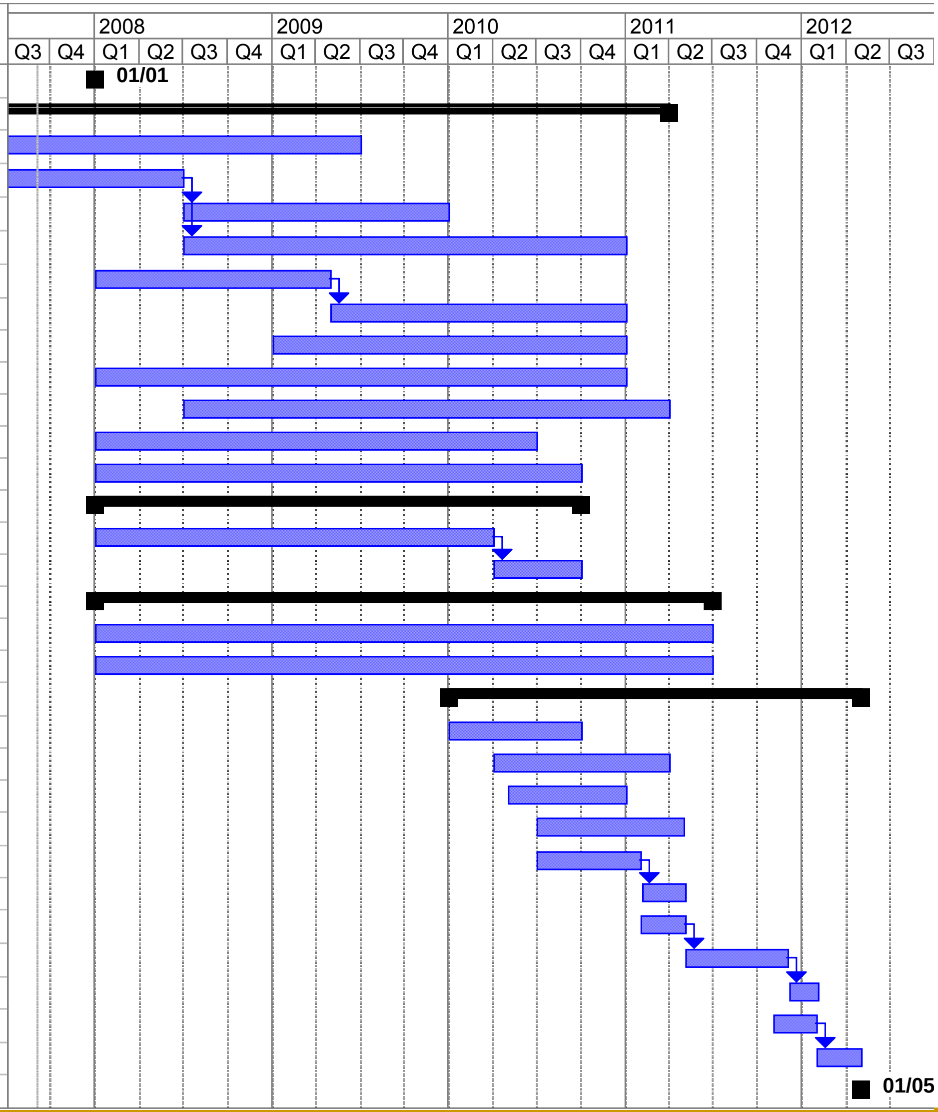
4 different structures,
(RFQ, DTL, CCDTL, PIMS)

Ion current: 40 mA (avg. in pulse), 65 mA (bunch)

From M. Vretenar (CERN)

Linac4 Master Plan

ID	WBS	Task Name
1		**Linac4 project start**
2	**2**	**Linac systems**
3	2.1	Source and LEBT construction, test
4		Drawings, material procurement
5	2.2	RFQ construction, test
6	2.4	Accelerating structures construction
7		Klystron prototyping
8	2.6.2	Klystrons construction
9	2.6.1	LLRF construction
10	2.7	Beam Instrumentation construction
11	2.8	Transfer line construction
12	2.9	Magnets construction
13	2.10	Power converters construction
14	**5**	**Building and infrastructure**
15	5.1	Building construction
16	5.2,3,4	Infrastructure installation
17	**3**	**PS Booster systems**
18	3.1	PSB injection elements construction
19	3.2	PSB beam dynamics analysis
20	**4**	**Installation and commissioning**
21	4.1	Test stand operation (3 MeV)
22	4.2	Cavities testing, conditioning
23		Cabling, waveguides installation
24		Accelerator installation
25		Klystrons, modulators installation
26		Hardware tests
27		Front-end commissioning
28	4.5	Linac accelerator commissioning
29		Transfer line commissioning
30		PSB modifications
31	4.6	PSB commissioning with Linac4
32		**Start physics run with Linac4**

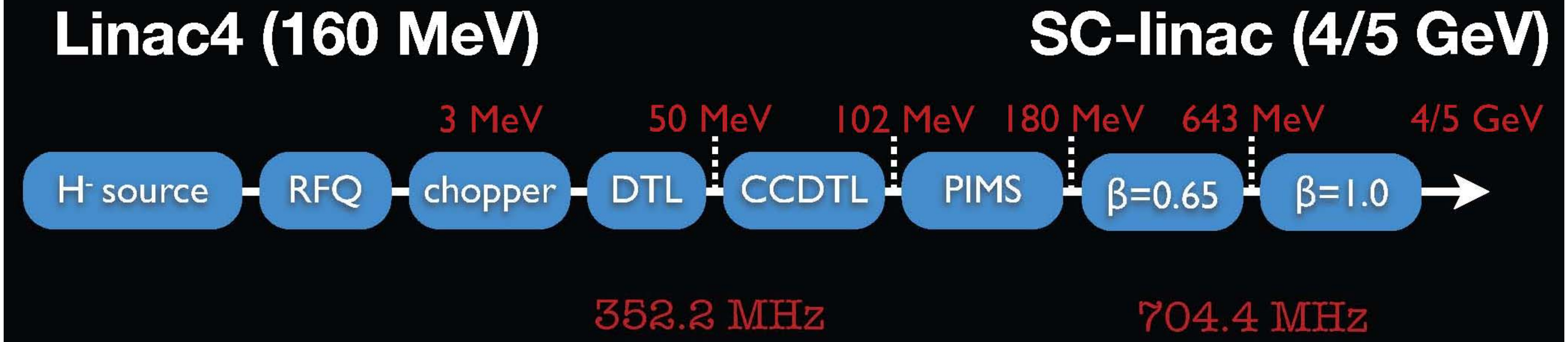


Planning based on the White paper requirements (end of project 2011), still to be confirmed for the building construction, which is on the critical path.

From M. Vretenar (CERN)

SPL block diagram

- Linac4 will inject at 160 MeV into the PSB,
- during construction and commissioning of the LPSPL, Linac4 will continue as PSB injector and provide beam to commission SPL/PS2,
- when PS2 is running, the “switching” area will be replaced with a 160-180 MeV normal conducting linac.



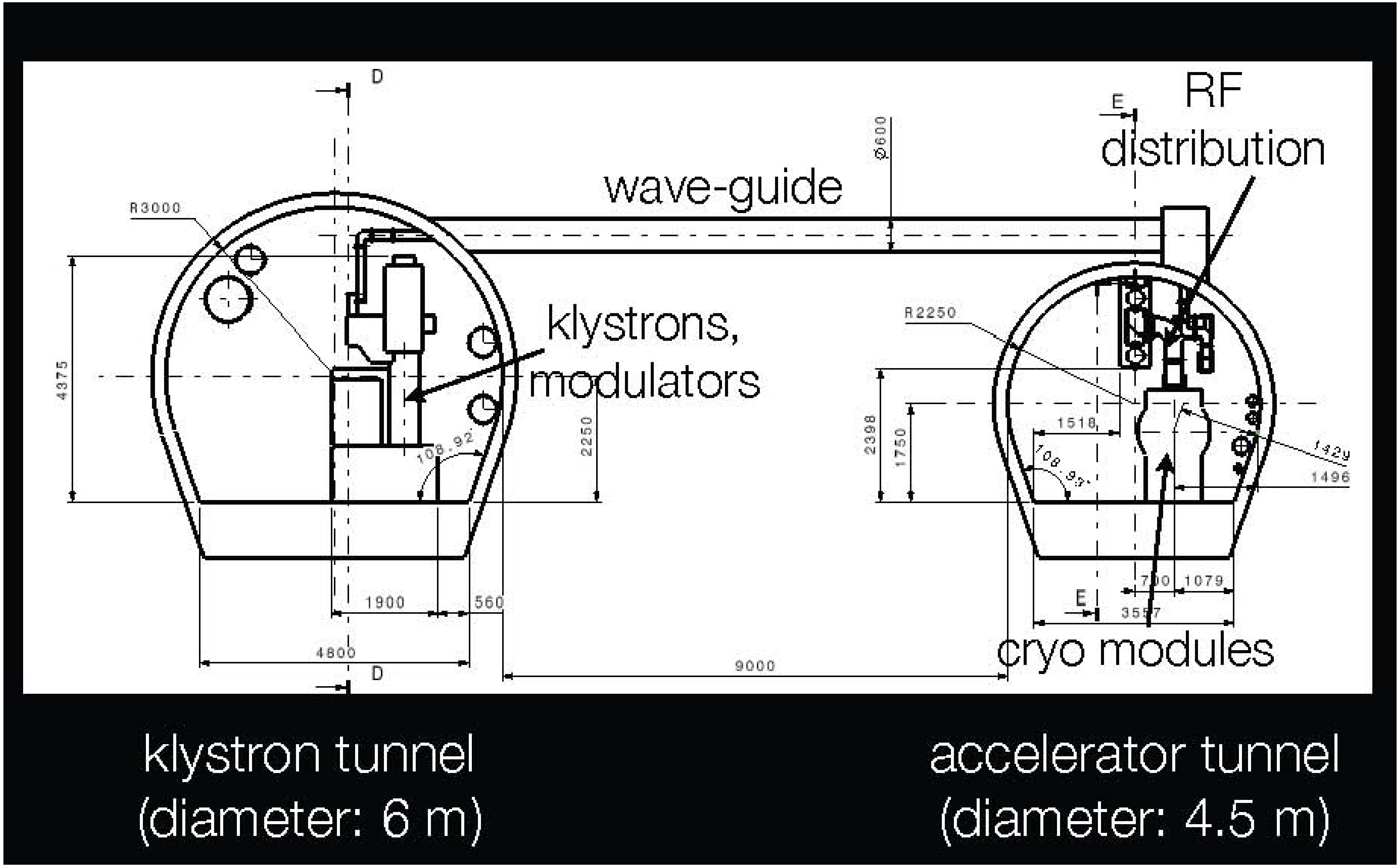
From F. Gerigk (CERN)

main parameters

SPL type	full-power	low-power
E [GeV]	5.0	4.0
P_{beam} [MW]	>4	0.192
f_{rep} [Hz]	50	2
$I_{average}$ [mA]	40	20
t_{pulse} [ms]	0.4	1.2
$n_{protons/pulse}$ [10^{14}]	1.0	1.5
Max. filling time PS2 [ms]	0.6	1.2
$n_{klystron}$ (Linac4 + SPL)	19+53	19+24
$n_{SC\ cavities}$	234	194
inst. $P_{RF(peak)}$ [MW]	220	100
$P_{facility}$ [MW]	38.5	4.5
$P_{cryo,\ electric}$ [MW]	4.5	1.5
T_{cryo} [K]	2	2
length [m]	534	459

From F. Gerigk (CERN)

Preliminary tunnel layout



From F. Gerigk (CERN)

To do list …

- finalise the siting exercise: feasibility study and civil engineering cost estimate for the end of 2007,
- FP7 bid for the construction of a full cryo-module with 2 cavities (+ 6 dummies?) in collaboration with CEA, INFN (?), DESY, IN2P3,
- FP7 bid for a high-power RF test stand at CERN, making use of the existing infrastructure in SM18 and equipping it for 704 MHz (5 MW klystron, RF distribution, modulator, etc),
- ... *and of course*: high-duty cycle H- source, SC quadrupoles, detailed beam dynamics, radiation protection, etc
- elaborate a technical design report including costs for a project decision in 2011/12.

From F. Gerigk (CERN)

Lessons on superconducting proton linacs

SNS Superconducting Linac

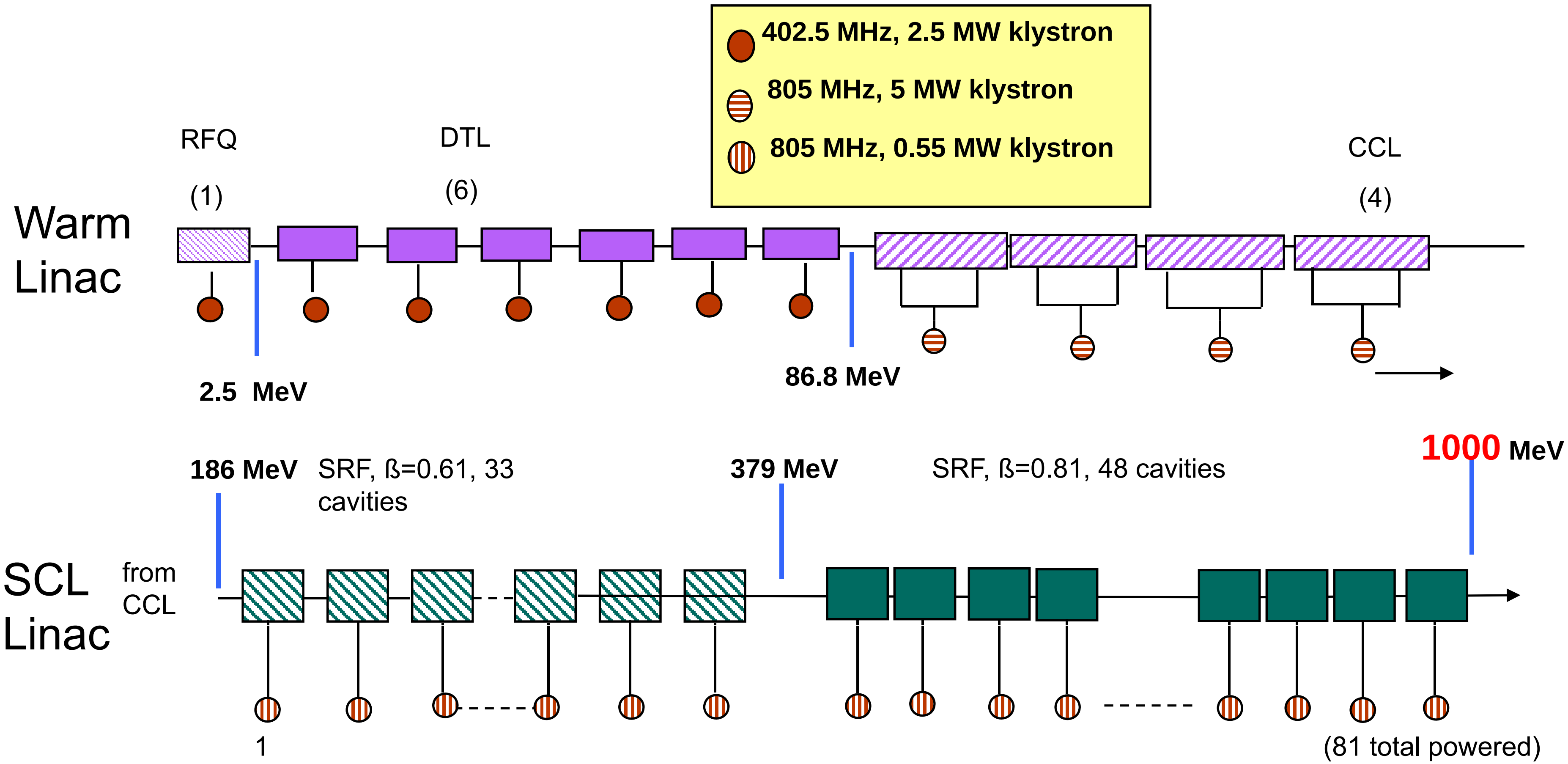
- Designed an built by Jefferson Laboratory
- SCL accelerates beam from 186 to 1000 MeV
- SCL consists of 81 cavities in 23 cryomodules
- Two cavities geometries are used to cover broad range in particle velocities
- Cavities are operated at 2.1 K with He supplied by Cryogenic Plant

Medium beta cavity

High beta cavity

From J. Galambos (SNS)

Layout of Linac RF with NC and SRF Modules

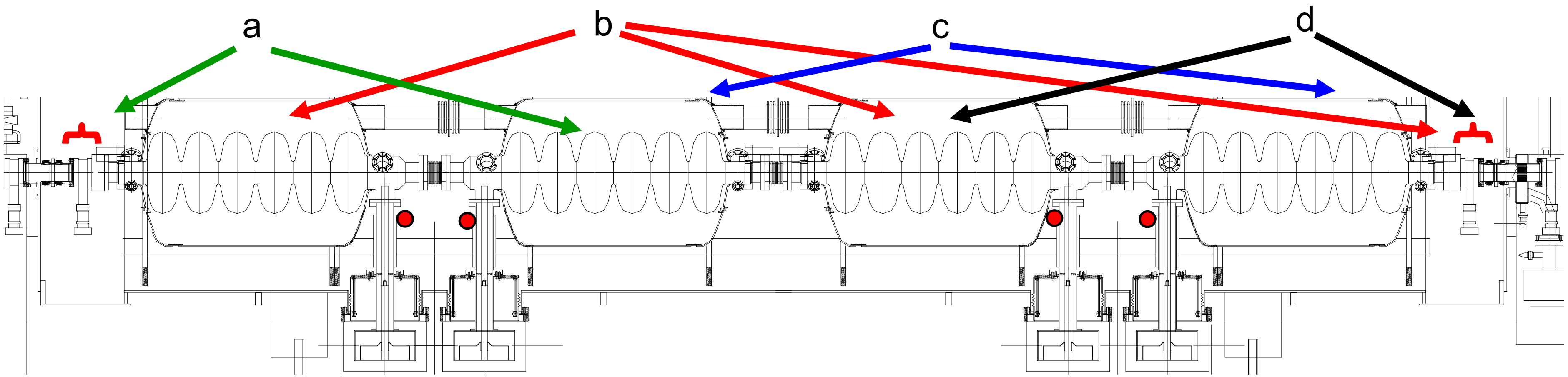


- SCL has 81 independently powered cavities
  - Many parts to keep running
  - Many values to set w.r.t. the beam

Cavity Limitations III - Collective behavior
(clear indication at higher rep. rate)

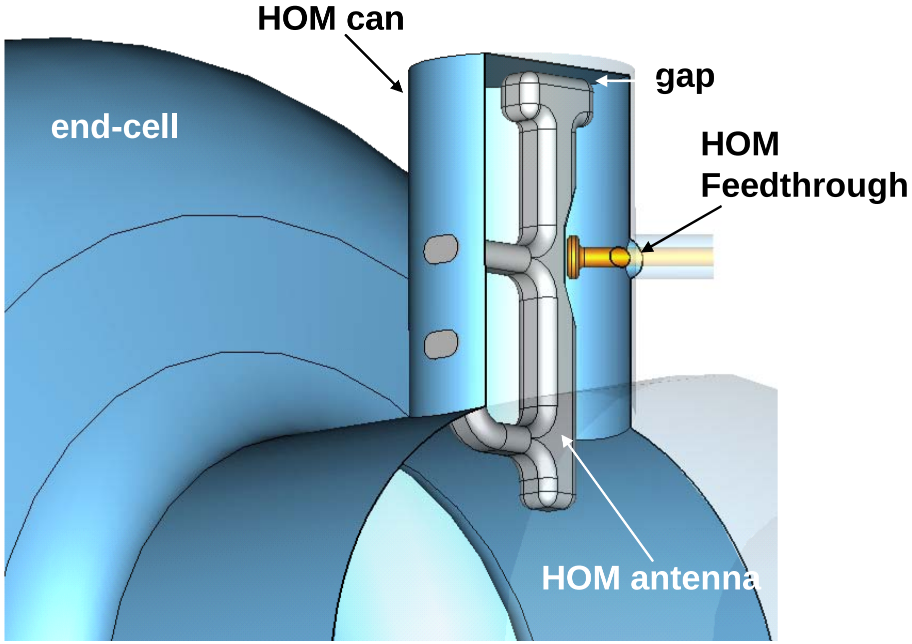
- Amplitude and phase setpoints of one cavity affect heating at other places
- Need to find setpoints that are friendly to neighboring cavities

Example:
CM13 individual limits 19.5, 15, 17, 14.5 MV/m
CM13 collective limits at 60 Hz ; 14.5, 15, 15, 10.5 MV/m



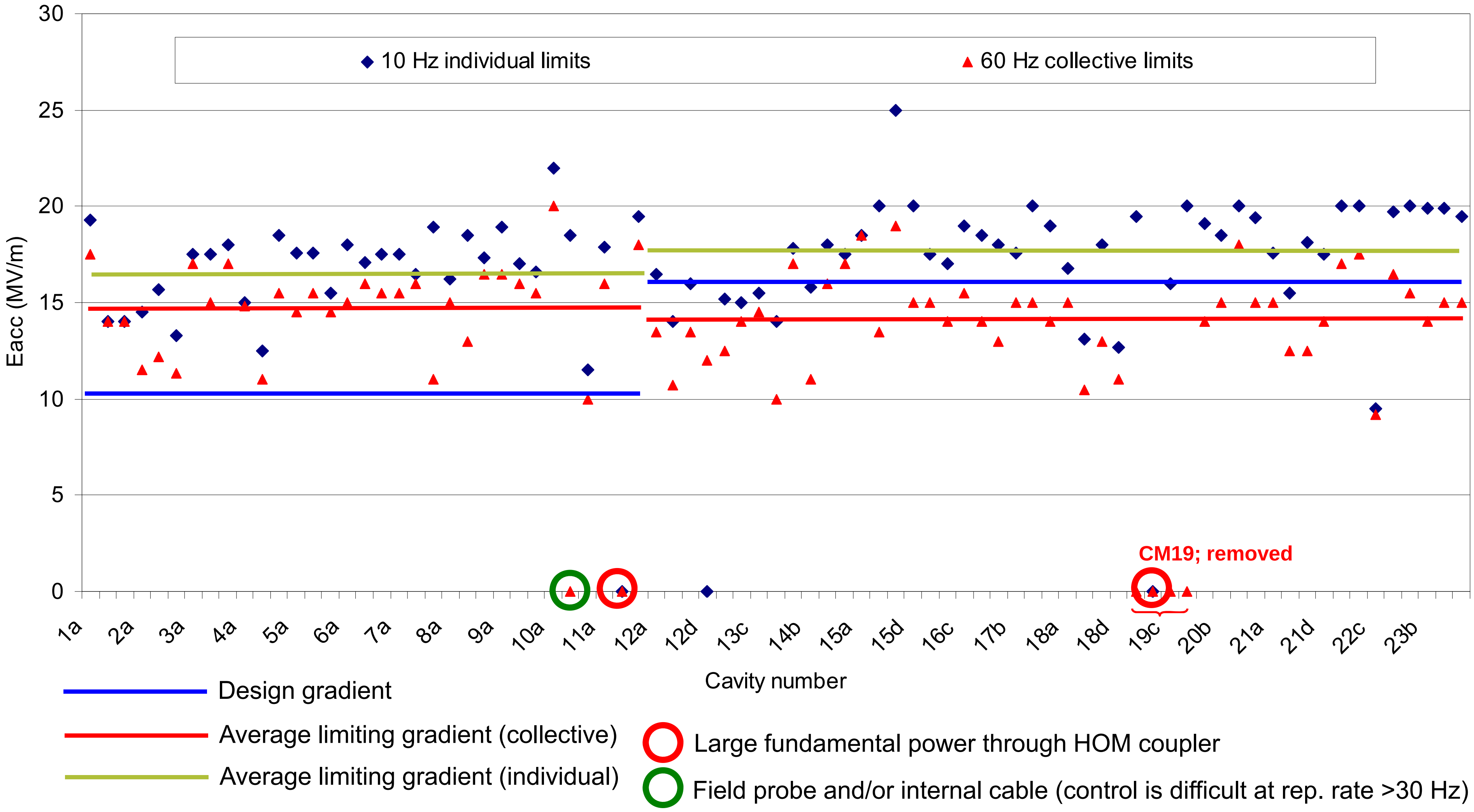
SCL Sub-component Concern I – HOM Coupler

- HOM couplers added as insurance even though probability that they are needed was very low
- HOM feed-through is susceptible to damage (FE, MP interactions + fundamental mode coupling)



- Some cavities are limited by coupling of fundamental power coupling (stray field + filter not set properly).
- We would not include HOM filters if we were starting over

Accelerating gradients and statistics



From J. Galambos (SNS)

SCL Cavity Phase Setup Times are Getting Shorter

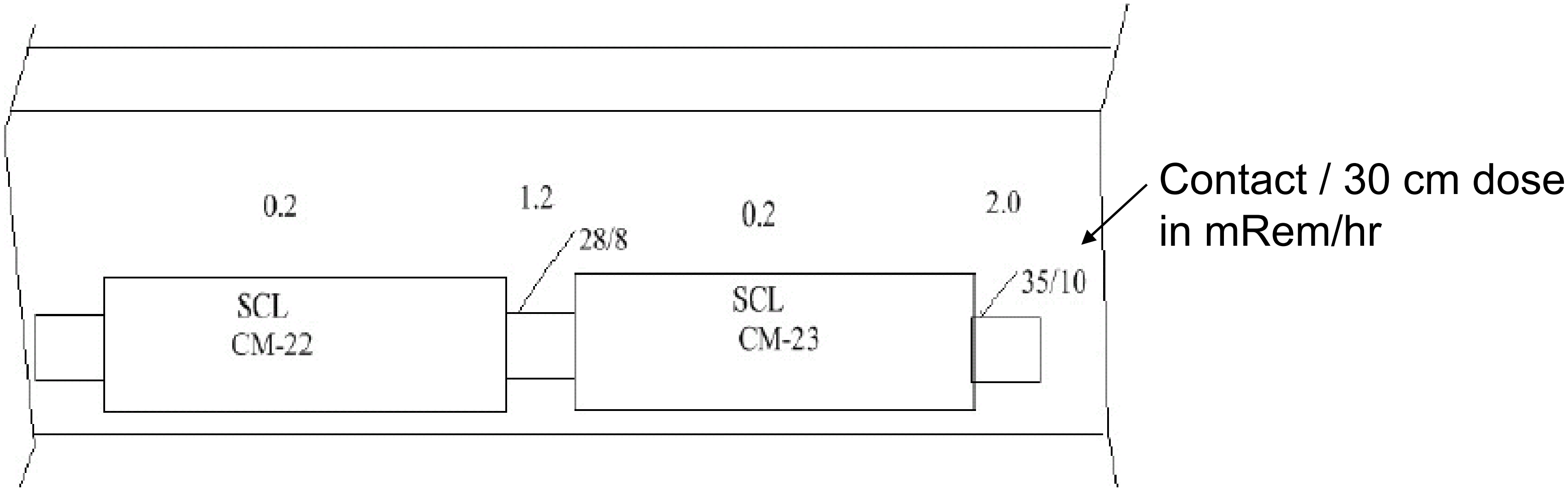
- August 2005: 48 hrs
  - 560 MeV, initial run, > 20 cavities off
- Dec. 2005: 101 hrs
  - 925 MeV, turned on all planned cavities
- July 2006: 57 hrs
  - 855 MeV
- Oct 2006: 30 hrs
  - 905 MeV, used established cavity turn on procedure

} Power cavities on sequentially

- Jan. 2007: 6 hrs
  - 905 MeV, beam blanking used, which allowed all cavities to be on during the tuning process
- *The procedures used to setup the superconducting linac have matured, and the setup time is now minimal*
- *Still exists a need for fast recovery from changes in the SCL setup*

From J. Galambos (SNS)

Beam Loss / Activation



- SCL has a large aperture and should easily transport beam
- This past summer we observed higher than expected activation levels in some warm sections (with quadrupoles) between the cryomodules – not expected based on loss monitor levels
- Not well understood, possibly longitudinal loss
  - Purposeful detuning of the warm linac results in loss patterns with similar shape as the activation patterns
  - “Dark current” from the ion source ?

From J. Galambos (SNS)

Summary from SNS…

- We have been operating the SNS SCL for ~ 2 years with beam
- Generally it is quite forgiving
  - Run with many cavities off / entire cryo-module removed / gradients far from design
  - Need tools to adapt to rapidly changing conditions
- Cavities are like individuals – each has it's own set of difficulties / strengths

From J. Galambos (SNS)

APD

Fifth International Workshop on the Utilisation and Reliability of High Power Proton Accelerators

Mol, Belgium,
6-9 May 2007

EUROTRANS
- EUROPEAN RESEARCH PROGRAMME FOR THE TRANSMUTATION OF HIGH LEVEL - NUCLEAR WASTE IN AN ACCELERATOR DRIVEN SYSTEM

Reliability of a s.c. linac from the ADS perspective

Revised version for:
CARE-HHH-APD BEAM'07
CERN, 1-5

Paolo Pierini, INFN Milano LASA

with many contribution from DM1/WP1.3-Accelerator (IPNO/CEA/IBA/IAP/INFN) and ENEA

From P. Pierini (INFN)

Overall EUROTRANS Goals

- Work towards a **European Transmutation Demonstration** (ETD) in a step-wise manner

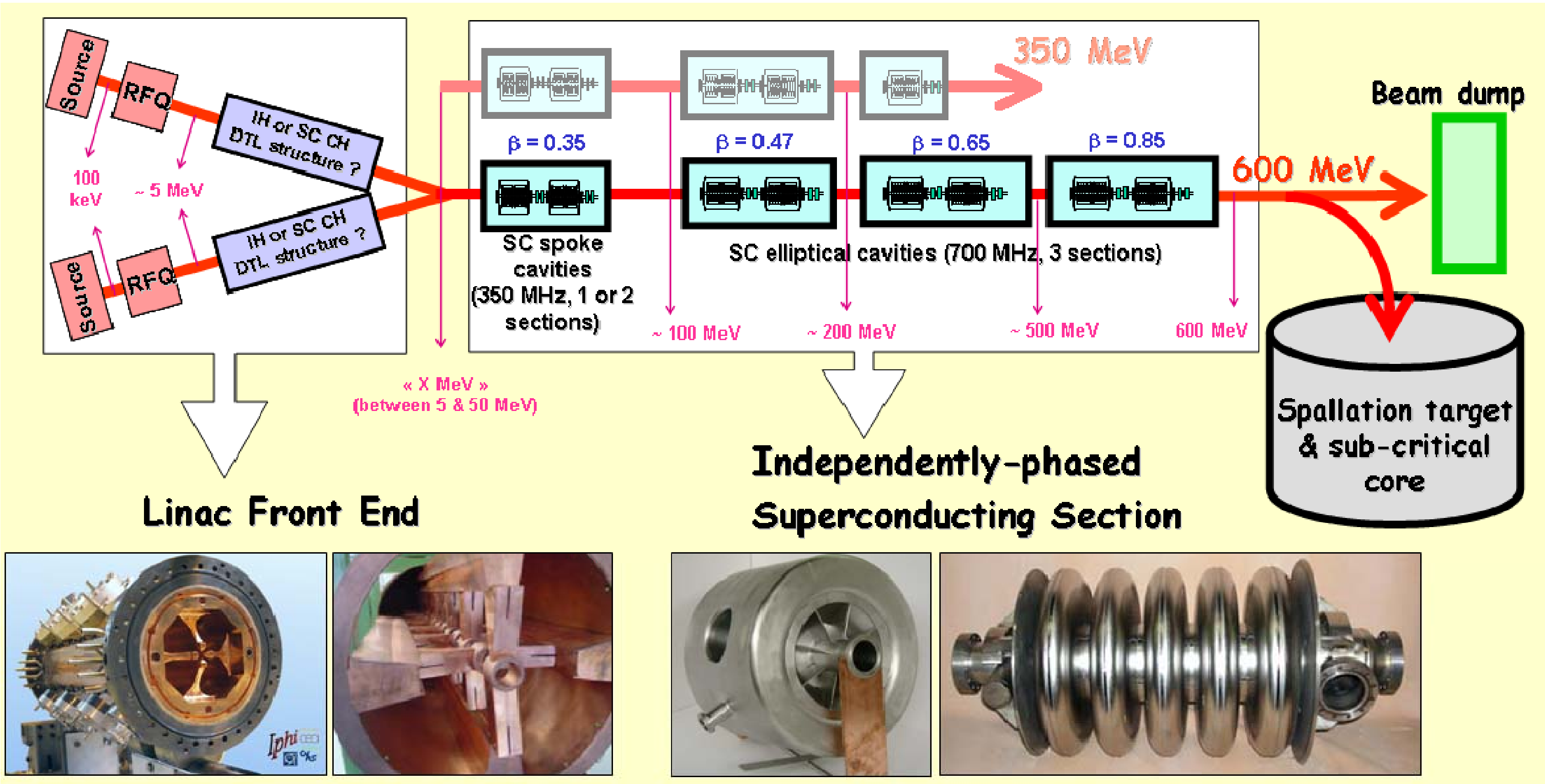
- Advanced design of a 50 to 100 MWth e**X**perimental facility demonstrating the technical feasibility of **T**ransmutation in an **A**ccelerator **D**riven **S**ystem (**XT-ADS**)
  - realization in a short-term, say about 10 years

- Generic conceptual design (several 100 MWth) of a modular **E**uropean **F**acility for **I**ndustrial **T**ransmutation (**EFIT**)
  - realisation in the long-term

From P. Pierini (INFN)

Accelerator workpackage

- Accelerator design performed in the PDS-XADS program
  - Choice of **superconducting linac**
  - Modular: same concept for Prototype and Industrial scale



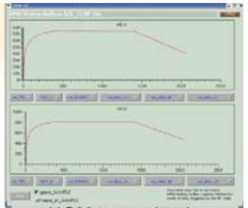
From P. Pierini (INFN)

Design issues

- Often many “reliability” problems can be truly identified as component design issues (weak design) or improper operation (above rated values)
- e.g. very successful SNS operation
  - concerns due to components providing non critical functionalities but with failure modes with drastic consequences

HOM couplers

- At Jlab
  - 2 feedthroughs leaked after testing
- At SNS
  - 11b (HOMB), 19b (HOMA) off due to excessive fundamental mode coupling
  - ~10 cavities show deformed transmitted power waveforms
  - Most inline attenuators were damaged during turn on and operation (transient power surge, related to field emission bursts)
  - Operational gradients limited and some cavities are off to prevent possibility of HOM feedthrough failure



HOM transmitted power curves (log)

TESLA Technology Collaboration Meeting
Fermilab April 23-26, 2007
Oak Ridge National Laboratory

Operations of SNS SRF

- **Cold Cathode Gauges**
  - Degradation of response and decreasing reliability (interlock replacement)
- **HOM Filters**
  - Distorted transmitted power waveforms
  - Feedthrough and attenuators failures
- **Field emission**
  - Relationship to quench, HOM, FPC
  - Field emission cross talk
  - Field emission cryogenic load

TESLA Technology Collaboration Meeting
Fermilab April 23-26, 2007
Oak Ridge National Laboratory
U. S. Department of Energy
UT-Battelle
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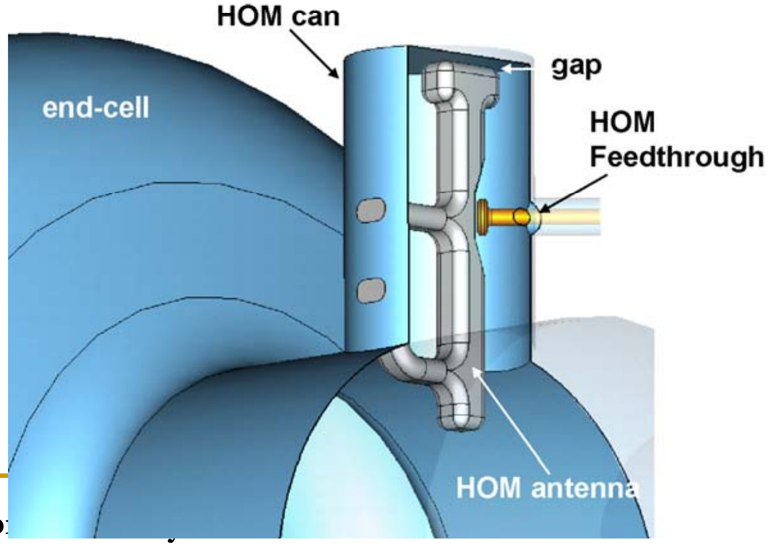


From P. Pierini (INFN)

Parts count

- With a “parts count” estimate we come to an obviously short MTBF ~ 30 h
- Split into:
  - Injector: 7.7%
  - Spoke linac: 45.4%
  - High energy linac: 43.5%
  - Beam line: 0.6%
  - Support systems: 2.7%

- Of course, the highest number of components is in the linac (nearly 100 RF units each, with each RF units having an MTBF of 5700 h...
- ***That already suggests where to implement strategies for redundancy and fault tolerance implementation***

From P. Pierini (INFN)

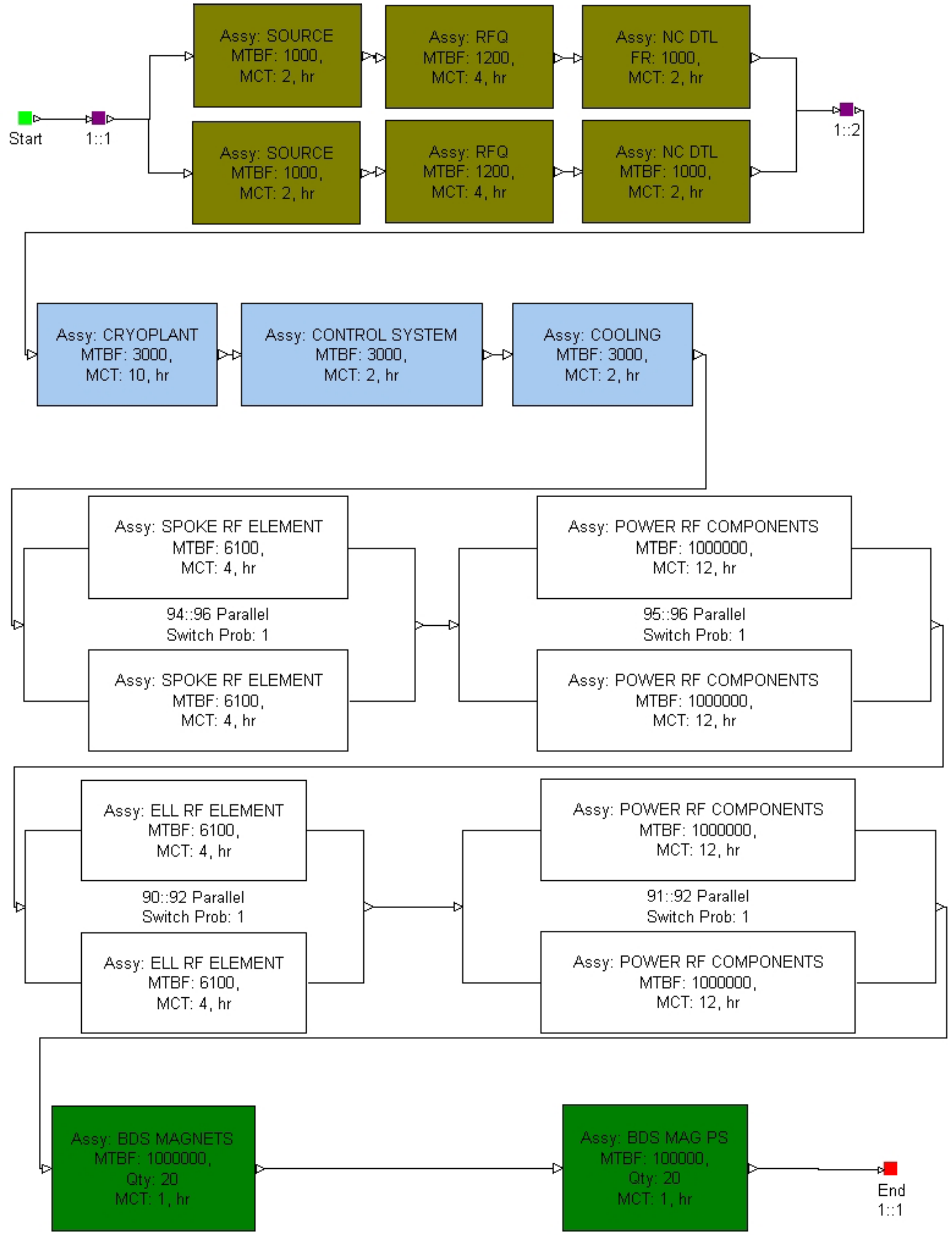
Final Scheme – Split RF Systems

- Keep 2 sources
- Split RF Units
  - Out of tunnel
    - Immediate repair
    - Any 2 can fail/section
  - In tunnel
    - 1 redundant/section
    - Repair @ system failure

System MTBF	**550 hours**
Number of failures	**3.8**
Steady State Availability	**97.9 %**

- Increasing only MTBFx2 of support systems

System MTBF	**720 hours**
Number of failures	**2.80**
Steady State Availability	**99.1 %**



From P. Pierini (INFN)

Conclusions (from ADS perspective)

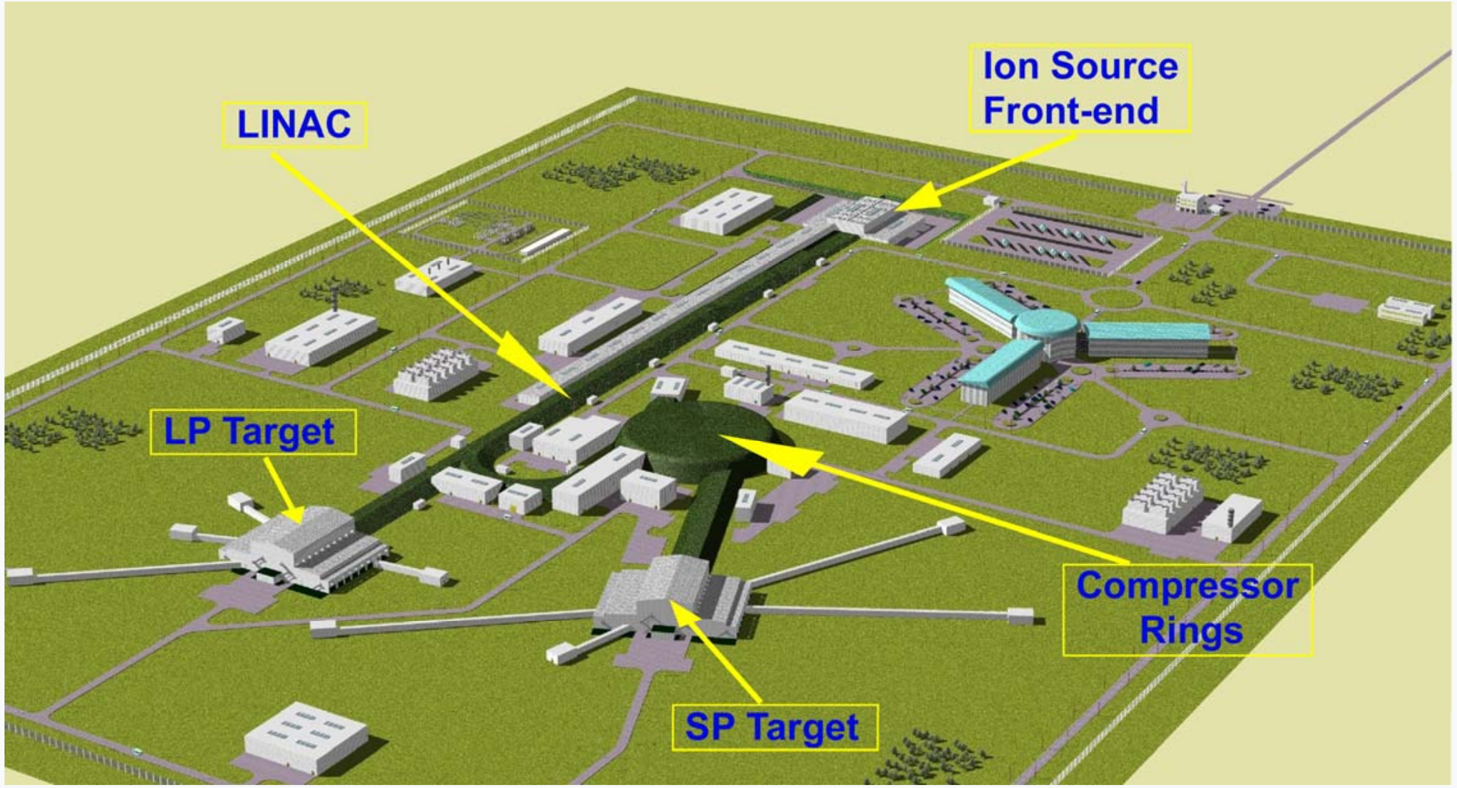
- Even in the absence of a validated reliability database for accelerator components the standard reliability analysis procedures indicate where design effort should be concentrated:
  - **providing large degree of fault tolerance whenever possible**
    - Meaning: fault detection, isolation and correction procedures
  - providing additional design effort aimed at **longer MTBF only in critical components**

- Study here is an illustration of how, with minimal “tweaking” of the component MTBF, a simple model for an accelerator system can be altered (adding redundancy and fault tolerance capabilities) in order to meet the ADS goals

From P. Pierini (INFN)

Synergies with other projects

Full ESS Facility: 5 MW SP & 5 MW LP target

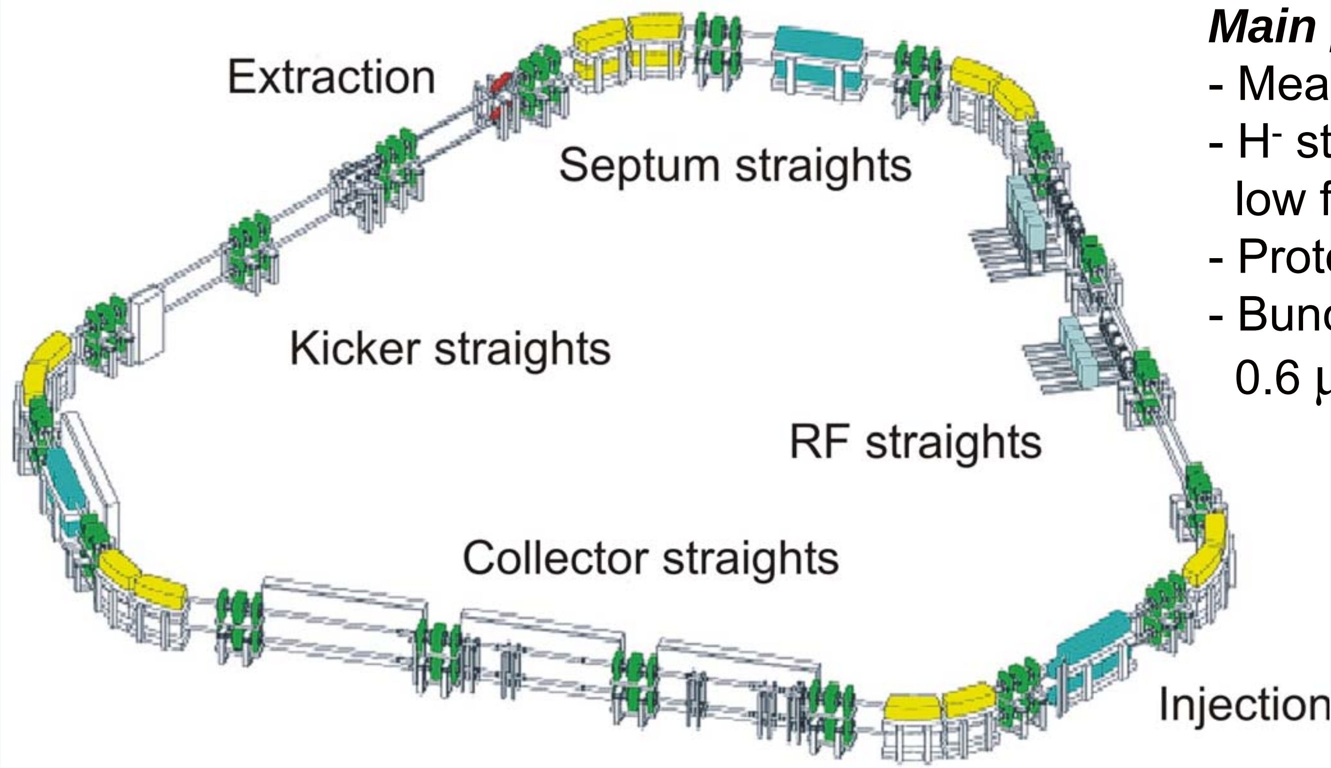


Size of 850 m x 1150 m

ESS facility consists of a 10 MW, H^- accelerator capable of delivering 5 MW, 1.4 μs pulses to a short pulse (SP) target at 50 Hz & 5 MW, 2 ms pulses to a long pulse (LP) target at 16 2/3 Hz. Both targets have 22 beamlines & liquid Hg is choosen as material.

From K. Bongardt (ESS)

Two stacked 1.334 GeV accumulator rings

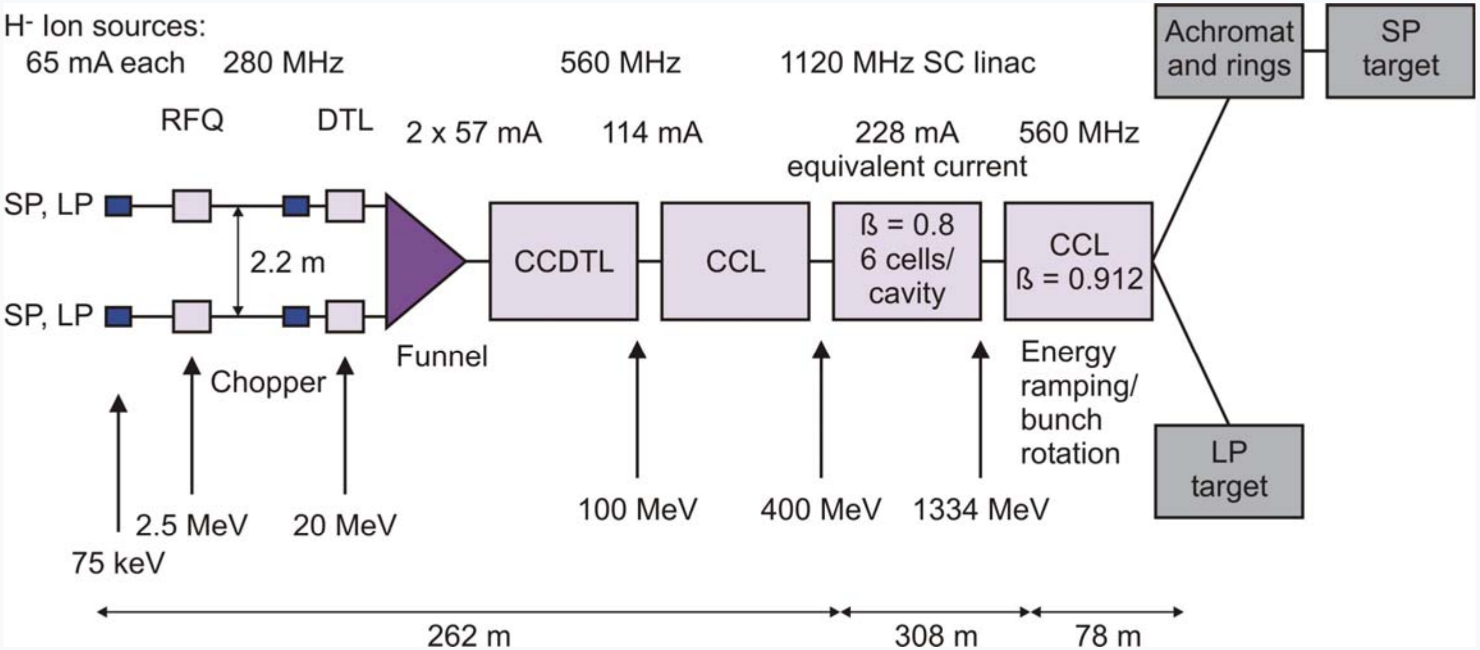


Main parameters:
- Mean radius 35m
- H^- stripping foil inside low field dipol
- Protons/ring 2.34 x 10^{14}
- Bunch, pulse at target 0.6 µs, 1.4 µs

• Chopping the incaming beam at 2.5 MeV helps minimizing the ring beam losses and reduces radiation damage.
Transverse & longitudinal profiles of injected H^- beam are cleaned by stripping foils in large 180 ° achromatic bending section.

From K. Bongardt (ESS)

ESS SC Reference Linac: 114 mA H^- beam, 1.334 GeV



- Short description: 2 x 65 mA H^- beams are combined together at 20 MeV in a funnel section. High frequency Superconducting (SC) cavities accelerate the beam from 400 MeV on. Moderate gradient of 10 MV/m in SC linac is used to keep RF power couplers within reasonable limits. After reducing energy spread by bunch rotation (BR) to ± 2 MeV, halo scraping in large 180 ° achromatic section.

From K. Bongardt (ESS)

ESS 2007, Changes in European Political Landscape

1. ESFRI Road Map 2006 (modeled after DoE 20-year facilities outlook) + strong desire of European Commission to implement this. ESS is high on this 35-project list – across all fields of science – as one very mature projects.

2. UK Neutron Review March 2006: UK should participate in European next generation project. Decision on feasibility study into 1 MW upgrade of ISIS postponed until European efforts fail.

3. Several very serious site candidates backed by national governments with money; see next slide.

From K. Bongardt (ESS)

ESS 2007, Synergies with CERN SPL linac

- Both high currents ESS linacs, either 114 mA H^- one or 150 mA H^+ one uses pulsed high ß SC cyromodules from 400 MeV. Timely construction of choosen ESS linac requires complete cyromodule as full power test-bed of pulsed SC cavities. ***Common interest*** with pulsed CERN SPL linac is evident .
- Depending on choosen ESS upgrade scenario, also low energy chopping line is required, maybe even for 150 mA H^+ linac. If a dedicated low power target station, like ISIS 2. target or planned SNS LW target, becames of interest for ESS upgrade, then beam intensity of 1 ms pulse can by 50 % reduced in low energy chopping line.
  Common interest with pulsed CERN SPL linac is evident .

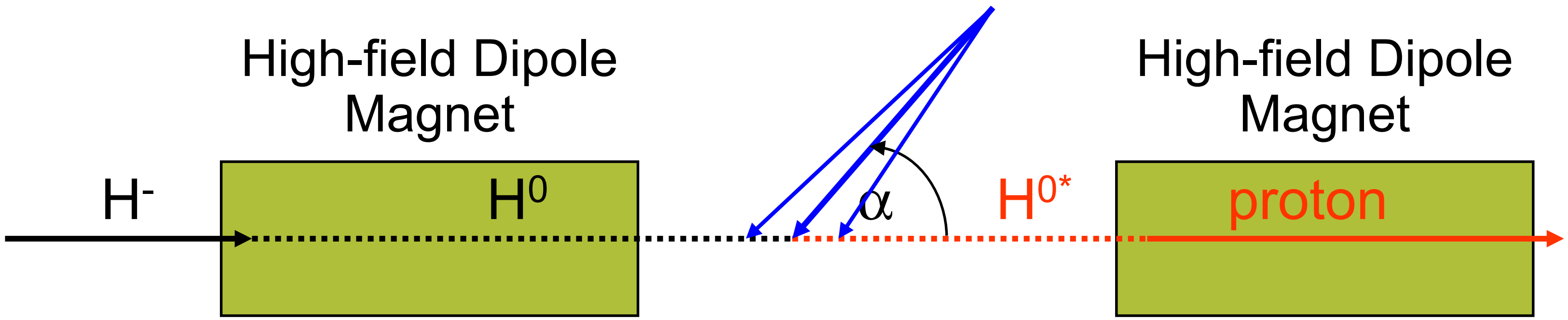
From K. Bongardt (ESS)

Laser H- ion stripping: Three-Step Stripping Scheme

Main problem –beam energy spread

- Our team developed a novel approach for laser-stripping which uses a three-step method employing a narrowband laser

$$f(1->3) = f_{laser}\frac{E}{E0}\left(1+\frac{v_{beam}}{c}\cos(\alpha)\right)$$



Step 1: Lorentz Stripping	Step 2: Laser Excitation	Step 3: Lorentz Stripping
$H^- \rightarrow H^0 + e^-$	$H^0\,(n=1) + \gamma \rightarrow H^{0*}\,(n=3)$	$H^{0*} \rightarrow p + e^-$

From V. Danilov (SNS)

Four Sets of Experiments Description

- 1st experimental run (December 2005)-no stripping seen. We wish we could get the answer to this puzzle
- 2nd experimental run preparation – laser moved to the table. It tripled the laser beam power
- Laser beam incident angle and beam parameters (energy of the ions) were more carefully measured
- Second run (March 2006) led to a first success (about 50% of stripping)
- Third run (August 2006) –successful (around 85% of stripping achieved)
- Forth (final) run (October 2006) – 90% stripping achieved, additional effects studied

From V. Danilov (SNS)

Summary and prospects of Laser H- ion stripping

1) POP experiment was successful;
2) Intermediate experiment (high efficiency up to 100 μs pulse stripping) on planning stage;
3) Necessary lasers can be built (we have quotes from some laser companies);
4) Preliminary ion optics investigation is done – the results are encouraging;
5) Beam recycling demonstration is now first priority.

After two options of beam recycling are explored, we start designing the stripping device for the long pulse stripping.

From V. Danilov (SNS)