ARW

4-6 February 2002, Grenoble

European Spallation Source (ESS) LINAC Reliability aspects and related budget considerations

R. FERDINAND, P. GIOVANNONI S. PALANQUE, N. PICHOFF

1 – Description of the ESS project

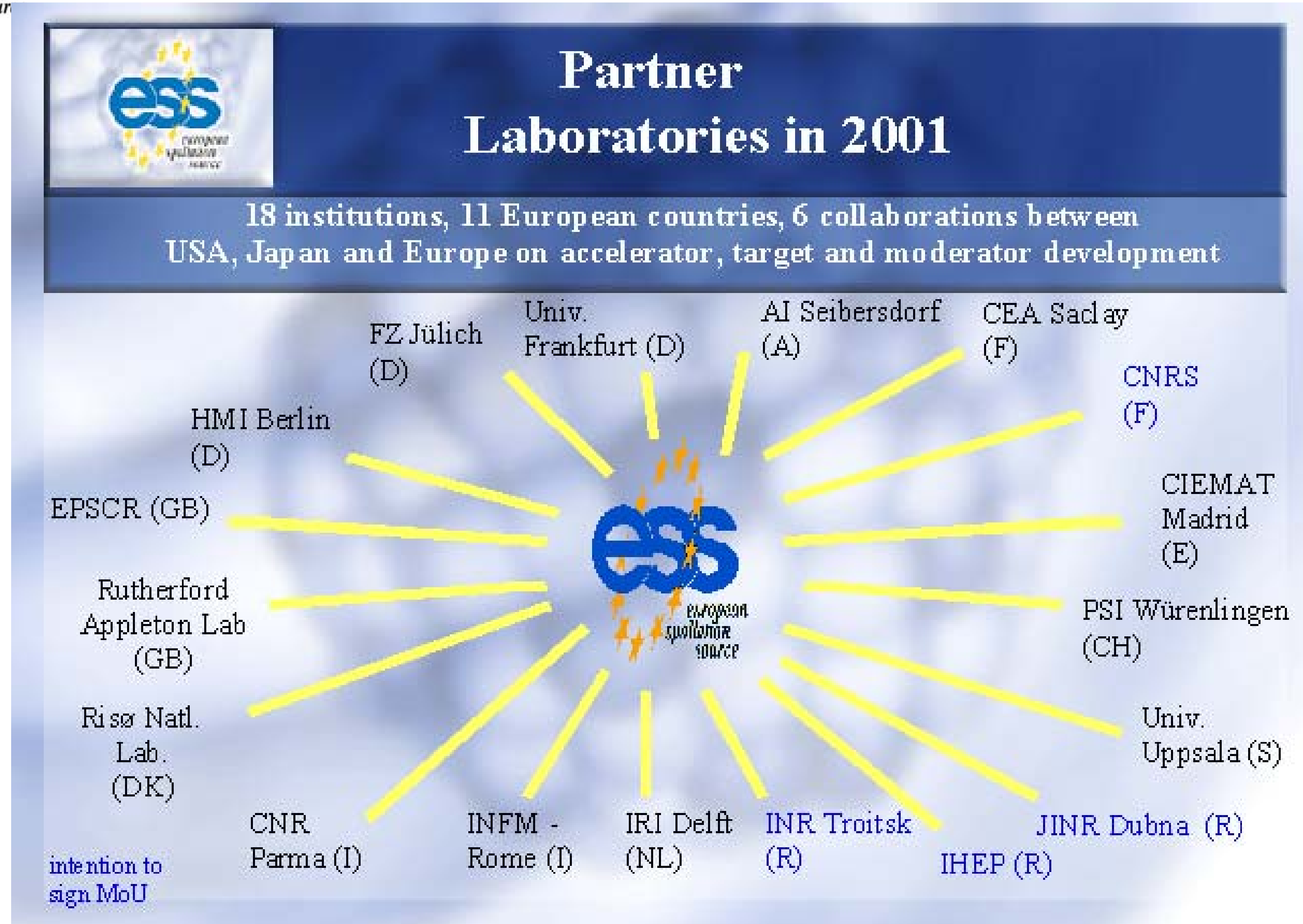
2 – RAM approach of the project

3 – Comparison with a non conservative design

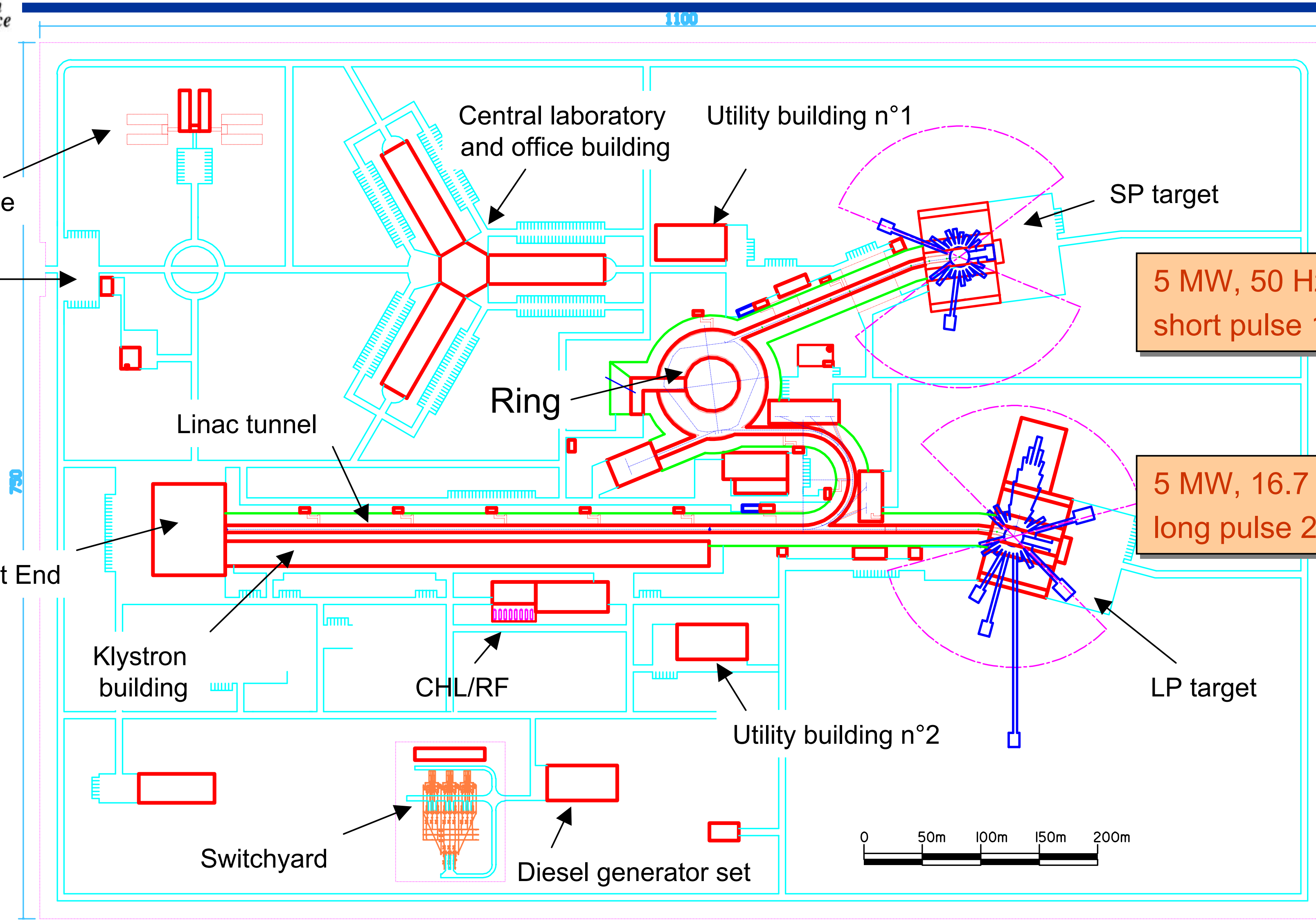
4 – Associated costs

5 – Conclusions

ESS Partners



ESS Layout



5 MW, 50 Hz,
short pulse 1.4μs

5 MW, 16.7 Hz,
long pulse 2.5ms

Why reliability in ESS ?

- Very powerful linac and rings (5+5MW machine)
- 5 500 hours/year as a USM (Using Service Mode) and 1 000 hours/year as a MDT (Machine Development Time)
- 44 instruments in operation
- Thermal choc on targets
- Full specs on day one (→standard and reliable options to be taken)

Reliability, availability at the design step

- Linac options
  - Low energy with 3 sources
  - SC linac parameters

- Conventional facility option
  - Electric distribution
  - Cooling system
  - Building in public access

Low Energy, RT linac (1/2)

Short Pulse:

- H^- sources are possible show-stopper (no such source in the world)
  - → 2 sources instead of one to relax the demand on source → 2 H^- branches and one funnel

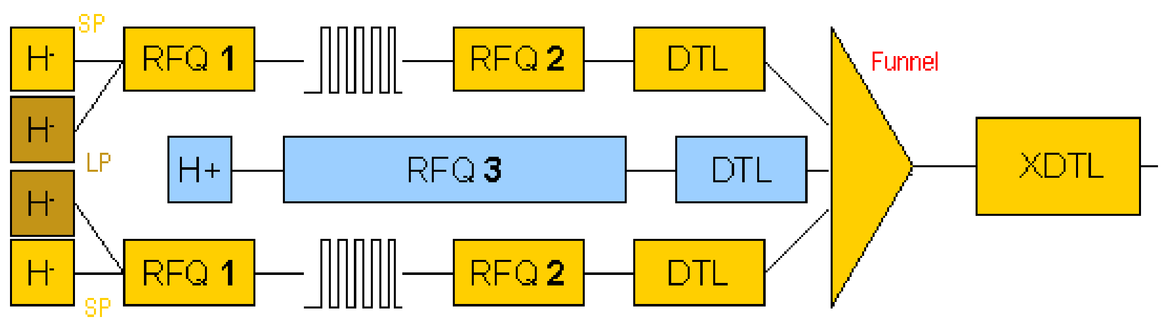
Long Pulse:

- Use of either 2 more dedicated H^- sources, or a dedicated proton line (preferable).

SP : 50 mA, 1.2 ms, 50 Hz

LP : 100 mA, up to CW

SP : 50 mA, 1.2 ms, 50 Hz



Low Energy, RT linac (2/2)

RFQs.

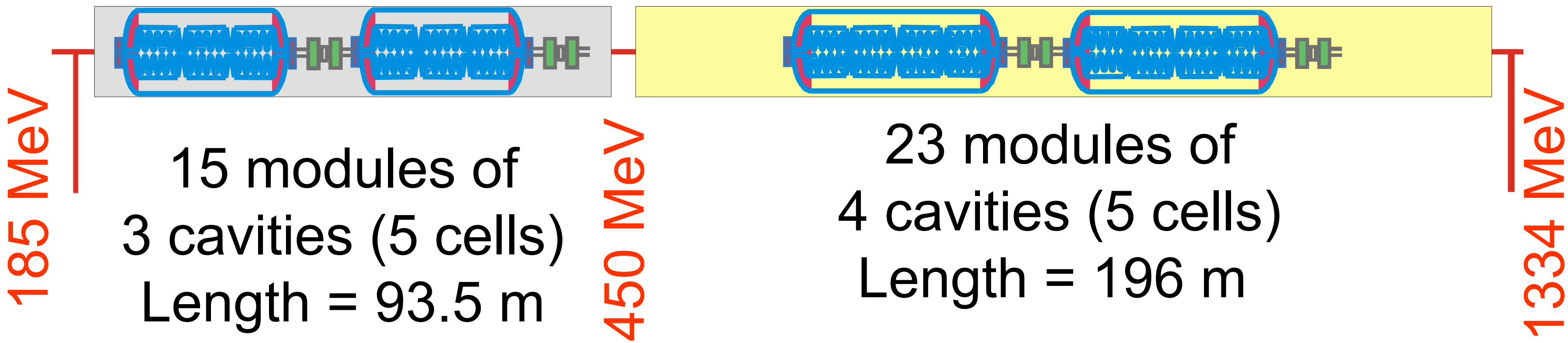
- Prefer to use a second RFQ behind the chopper line because they are dedicated device to efficiently bunch the beam → preserve the good beam quality as much as possible
- Design showing at least 99% of theoretical transmission to avoid radiations, losses of fragile particles and induced sparks. → *long to very long RFQs* → cost more (inefficient cavity, longer tunnel).
- Chopper line at 2 MeV to avoid activation of the 1st RFQ.

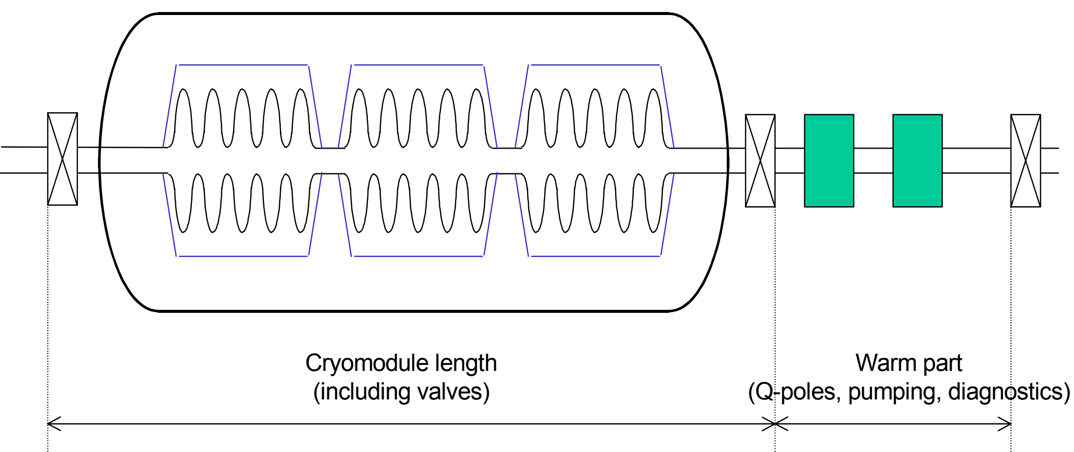
DTLs

- 5 MeV to allow classical EM quadrupoles

704 MHz, SC linac

β_{low} = 0.68 β_{high} = 0.86





	Bêta 0.68	Bêta 0.86
Nb cells / cavity	5	5
Nb cavities / module	3	4
Nb modules	15	23
Iris diametre (mm)	90	100
Lengh module (m)	4.3	6.475
Warm space (m)	1.85	2.05
Lattice periode (m)	6.15	8.525
Static load (W)	25	30
Dynamic load (W)	39	76
Total sector load (W)	960	2544

@2.1°K

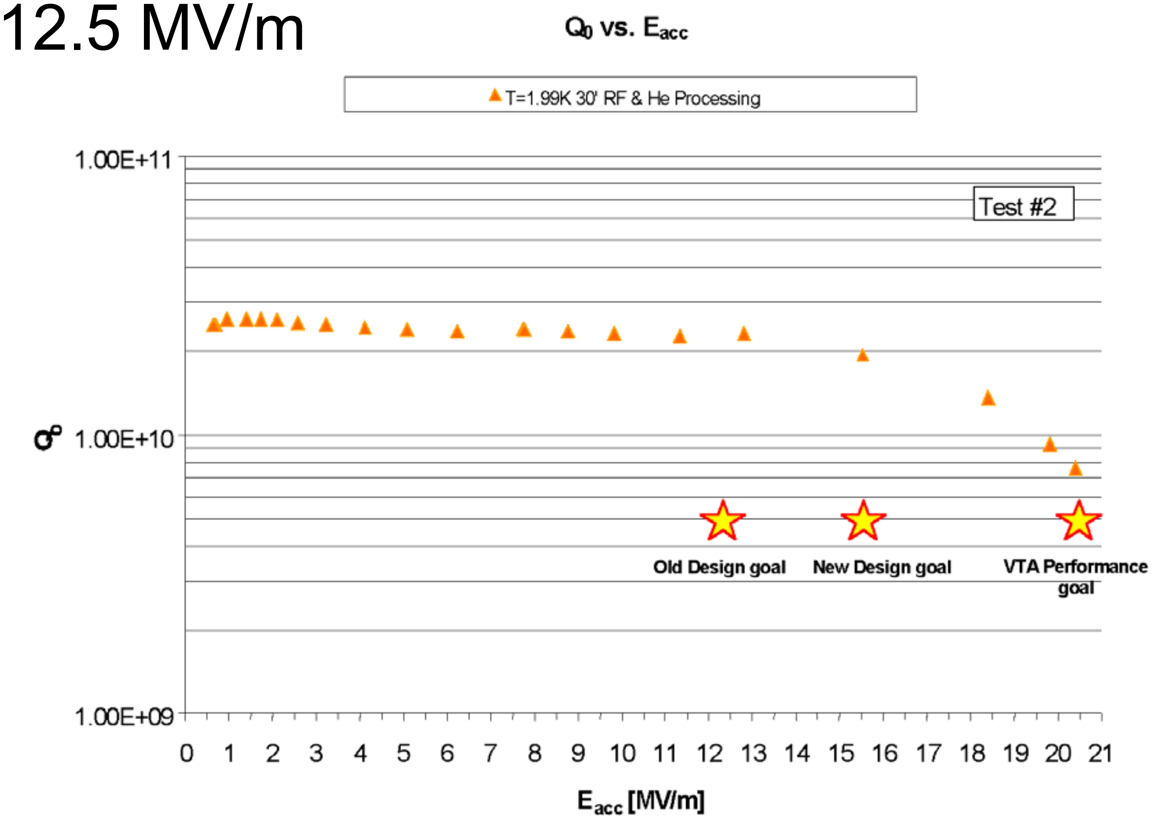
704 MHz, SC linac

Conservative design

- 50 mT max B_{peak}, 10.5-12.5 MV/m
- 800kW/couplers

•45 x 1.1 MW klystrons

•96 x 1.6 MW klystrons



Performance of 6-cell, β=0.81 cavity, stiffening ring at 80 mm. (SNS)

Power coupler capability

~ 1 MW rf power transferred on test stands at different places
highest power presently delivered with beam ≈ 380 kW cw (KEKB)

SNS coupler : design power of ≈ 500 kW
first tests already started: promising results even w/o dc biasing
750 kW on test stand (at room temperature) limited by RF power source
around 2 MW more recently must be confirmed at cold temperature

for the ESS linac : we can rely on a 800 kW coupler
assuming 2 couplers / cavity ⇒ total RF power of 1.6 MW available / cavity
*no technical risk but constraint on the mechanical design of the cryostat

higher power in a reliable way needs more R&D: efforts are going on
(Jlab/LANL for SNS, LAL-Orsay/DESY for TESLA)

Alban Mosnier.

RF power system

Basic principles for the RF system design :

- **Klystron power output** = beam power / cavity + 32% extra power

  circulator + waveguide losses (6%)
  waveguide distribution + coupler mismatches (6%)
  cavity field control (20%)

- **Large RF power range** (500 kW to 1600 kW) ⇒ different klystron types can be considered (efficiency depends on output power)

- **several klystrons driven by one modulator** ⇒ reduction of the HVPS cost and increase of the reliability (lower number of HVPS)

  with optimisation of klystron efficiency by adjustment of the high voltage setting (η_K = 65% at max power)

- **2 types of modulators** (designed for 2 different max. output High Voltage values)

  Ex. for 2 klystron families : max. efficiency & min. total cost of modulators when the klystron type changes at the medium- to high-beta transition

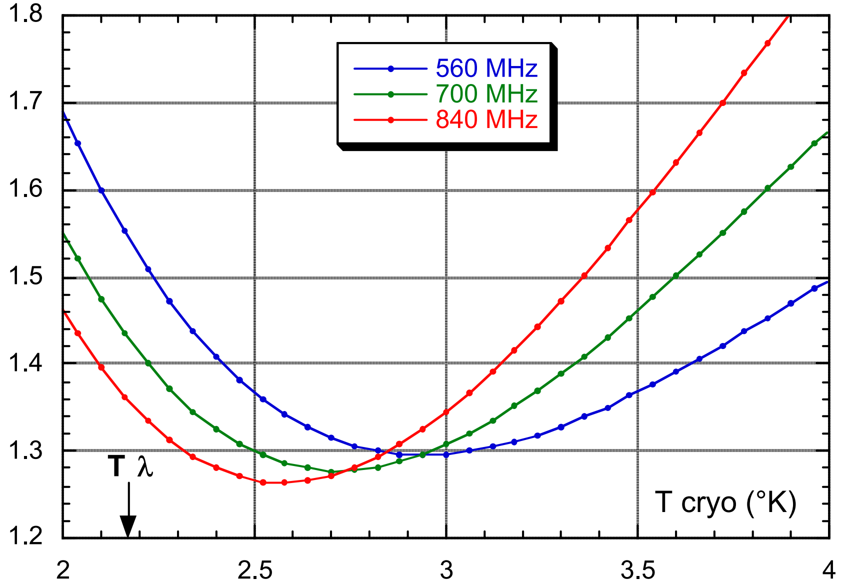
Cryogenic and cost aspects

operation costs lower at higher frequency :

even if cost optimum at higher temperature,
better to stay below the lambda point ~2.2°K
because cavity fields improve at superfluid helium

(highest fields are achieved)
⇒ extra costs higher at lower frequency

required power from the mains as a function of temperature for 3 frequencies



General advantage/disadvantage of SC techno

- Capital costs of both technologies look similar (difference in capital cost between NC and SC linac systems not significant over a reasonable gradient range (say, 10-20 MV/m)
- Operation cost for ESS parameters with 10% duty cycle (Cu dissipation ~ beam power) result in power saving of about 20 MW (not negligible)
- Flexibility from the large energy acceptance of the SC cavities, a SC linac should provide :
  - a greater availability. In case of failure of a pair of cavities, the beam can be recovered after linac re-tuning (not possible for NC linacs)
  - an upgradability potential. Final output energy can be increased by increasing the cavity fields, using experience and developments in the usable gradients (provided the RF source can be also upgraded)
- from the experience on existing installations, the SC technology shows a better operational availability (very stable cryogenic temperature, whereas NC systems require frequent retunings due to slow temperature drifts)

General advantage/disadvantage of SC techno

- Bore radius
  - Big Ratio of bore radius over rms beam size : safety factor related to possible beam loss, ➔ less losses = faster intervention
- Residual gas
  - Ultra-high vacuum from cryogenic system creates
    - less beam-gas stripping ➔ less beam loss in the linac, especially at the high energy end
    - Less diffusion, combine with errors ➔ less halo formation

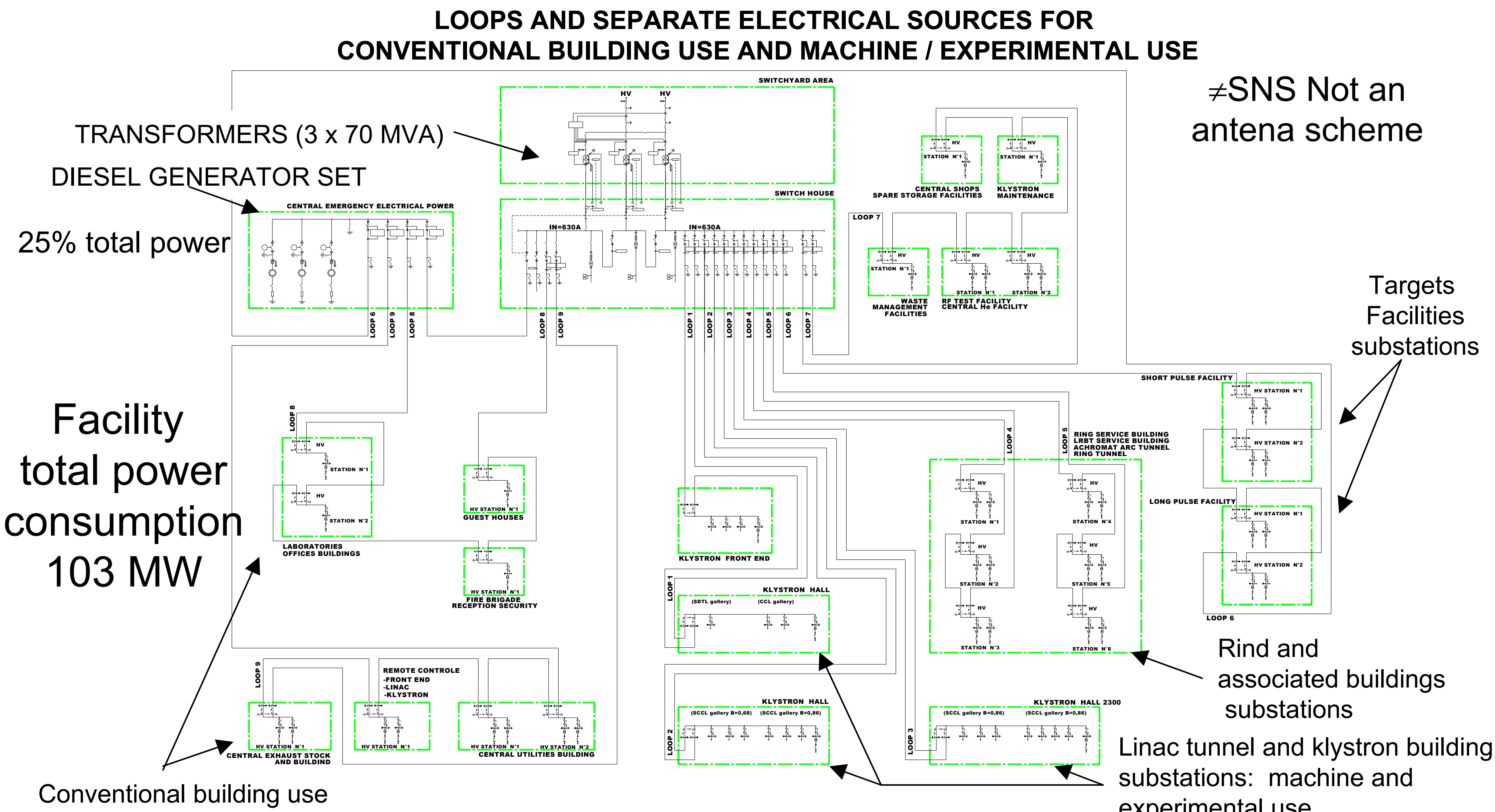
Options taken into account

Unless the request to decrease as much as possible the ESS costs, some availability options were kept:

- Low gradient in SC cavities
- 10% replacement klystron
- One cryomodule on a test stand
- Accelerator tunnel, Rings, transfer lines and klystron hall have air conditioning system (≠ SNS) → better cooling of the power supply.
- Electrical power distribution
- Cooling system
- All building in free access (maintainability)

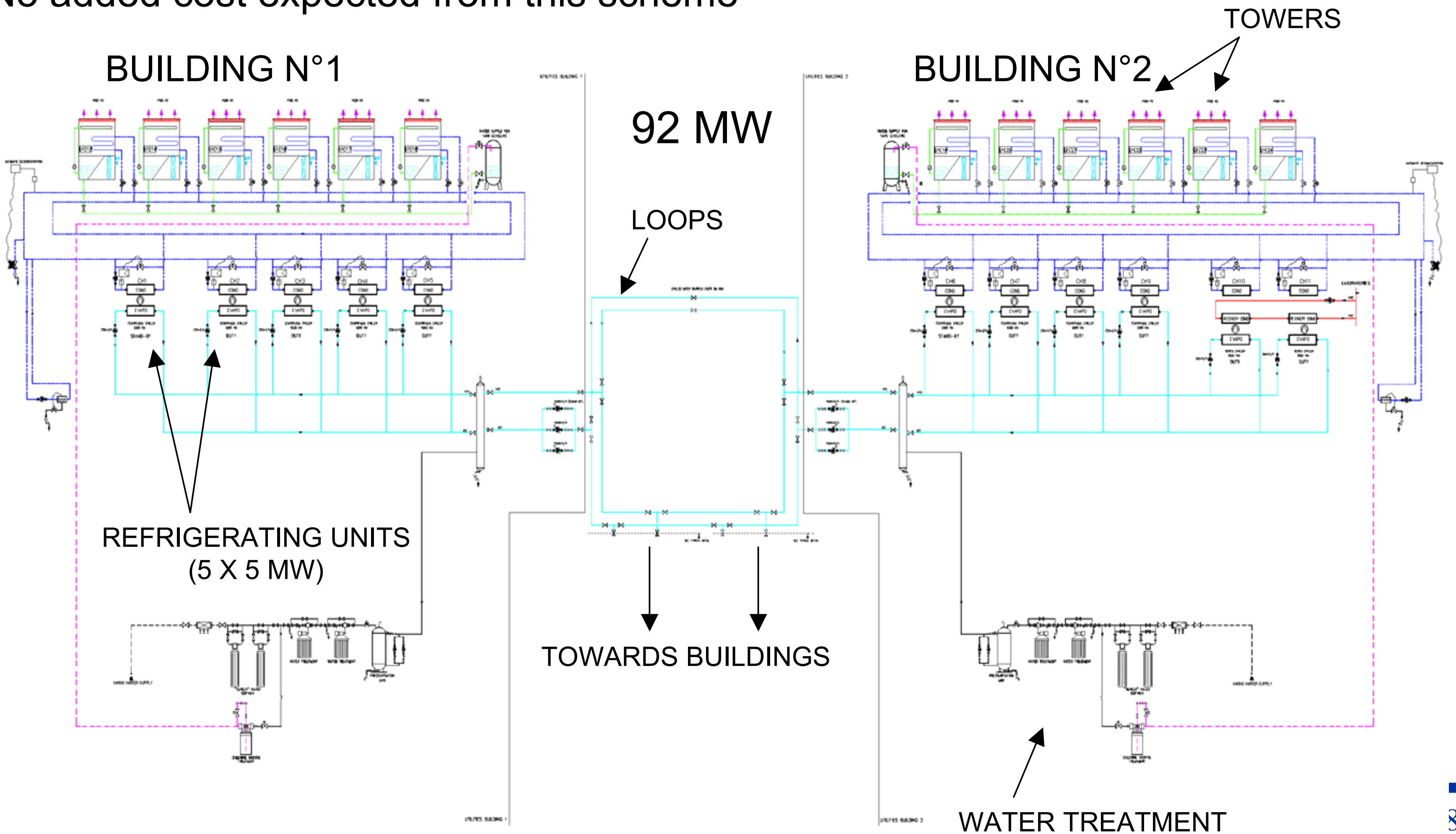
Electrical distribution

•All the electrical substations are on loops



Chilled water production and distribution

•For reliability and maintenance reasons, we have designed a water loop distribution on the site (water tower and chilled water)
•No added cost expected from this scheme



related budget considerations

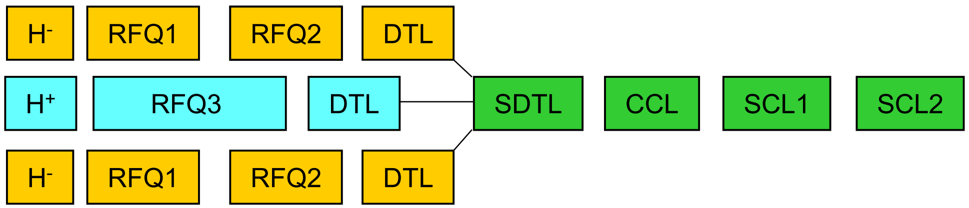
Options NOT taken into account in costing

- 30% margin on klystrons
  - 1.5MW klystrons used at 1.1MW peak max
  - Retuned with lower HT to decrease the breakdown rate
  - Gives a lower efficiency (65% down to 50%) and then increase the exploitation cost

- Margin on power supply.

- Redundancy on equipment and diagnostics.

Comparison with a non conservative design



50 mT (Bpeak)
0.8 MW/coupler, 2/cavity
1.1 MW and 1.6 MW klystrons

SP : H^-, 50 mA, 1.2 ms, 50 Hz

LP : H^+, 100 mA, 2.5ms 17Hz
3 sources

Conservative	**β1**	**β2**
Modules	15	23
Cavities/module	3	4
Cells/cavity	5	5
Length (m)	93.5	196
Non Conservative	**β1**	**β2**
Modules	13	15
Cavities/module	2	4
Cells/cavity	6	5
Length (m)	70	128

β_1=0.68
β_2=0.86

SP : H^-, 50 mA, 1.2 ms, 50 Hz

LP : H^-, 100 mA, 2.5ms 17Hz
One source

80 mT (Bpeak)
1.3 MW/coupler, 2/cavity
2 MW and 2.6 MW klystrons

Gains

The gains are:

- Shorter Linac
- Smaller building
- Less Klystrons
- Smaller front end, only one line
- Easier to tune (single particle type)

Capital cost

Only differences are shown.

		SC reference		SC less conservative	
		Medium beta	**High beta**	**Medium beta**	**High beta**
Accelerating structure	Nbr segment	15 @ 850k€	23 @ 950k€	13 @ 800k€	15 @ 950k€
	Total cost	**34.6**		**24.6**	
RF power	Klystron system	45 @ 530 k€	92 @ 580k€	26 @ 590k€	60 @ 640k€
	Total cost	**77.2**		**53.7**	
	HVPS	4 @ 1100k€	11 @ 1500 k€	4 @ 1500k€	10 @ 2400 k€
	Total cost	**20.9**		**30**	
Linac tunnel	Length	290 @ 13k€/m		198 @ 13k€/m	
	Total cost	**3.8**		**2.6**	
Klystron hall	Area	290×15 @ 1.7 k€/m²		198×15 @ 1.7 k€/m²	
	Total cost	**7.4**		**5.0**	
LE linac	H- lines	2×21.4		22.7	
	H+ line	1×17.9			
	Total cost	**60.7**		**22.7**	
Funnel		**8**			
Diesel engines and loops		**8.8**			
Central Helium Liquefier **Total cost**		3.5MW **13**		7MW **19**	
Grand total		**234.4 M€**		**157.6 M€**	

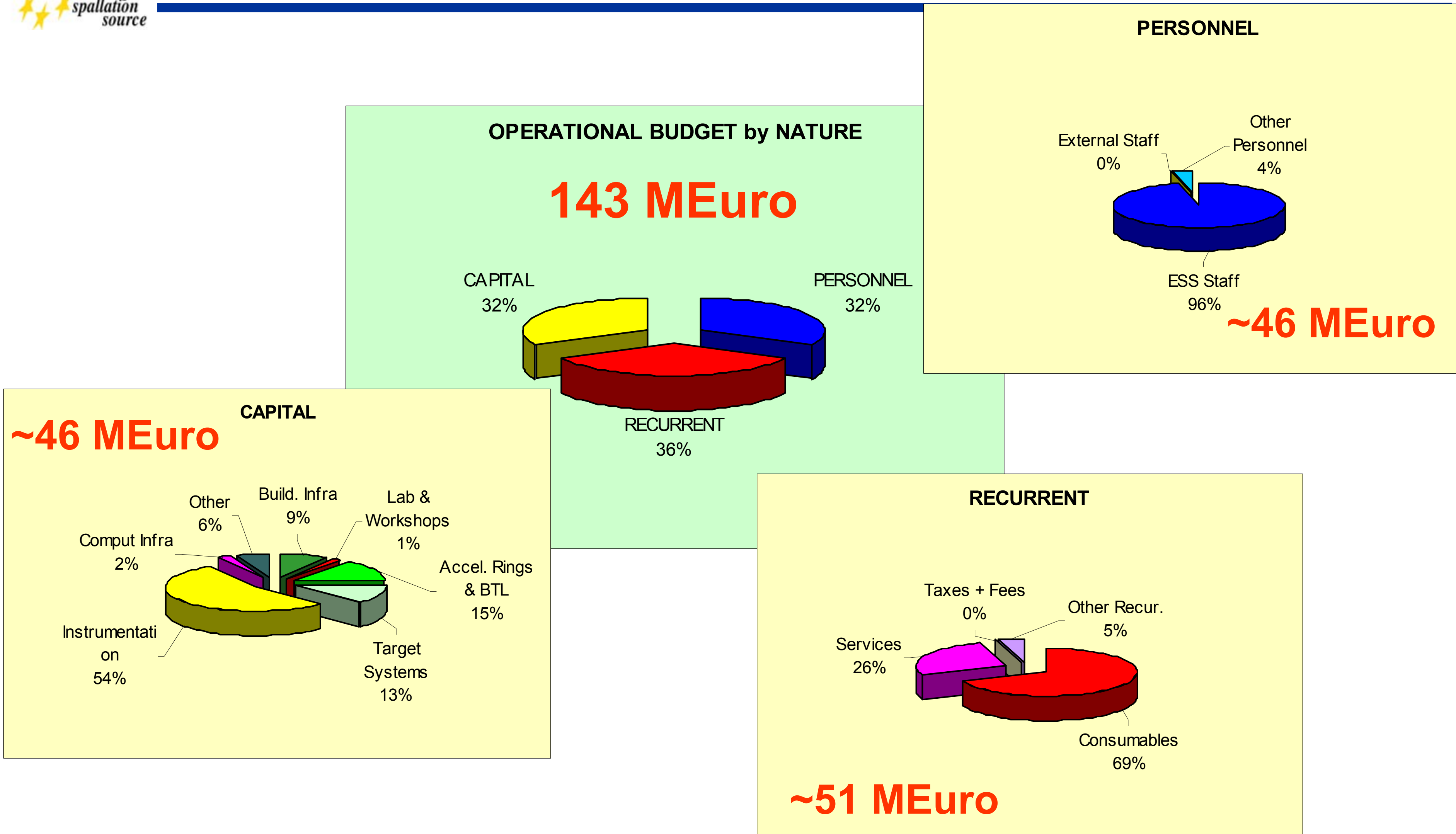
Δ = 76.8 M€

Operation cost (M€ w/o taxes)

	SC Linac		Less conservative SC Linac	
	medium-beta	high-beta	medium-beta	high-beta
Linac length (m)	290		198	
Pb/Pac efficiency (%)	33		38	
SC Pmains (MW) @10 MW	30		26	
Front end PMains	20		15	
P mains Cost (0.040 €/kWh)	13.5		10	
Cryo power (MW)	3.5		7	
10% klystron reniewal	2.2		2.9	

Δ ~ 1.3 M€

Yearly Oper. Budg. by Nature & Chapter



Conclusion

- The ESS Linac is very well advance in the design.
- Complete cost exists, crosschecked several time with SNS and other existing facilities
- Several RAM options are considered already at the design step
- A comparison was shown to evaluate further the cost of reliability
  - Almost 77M€ is included in the reliability approach. (~5% of the total ESS project cost of 1500M€)
  - The yearly operation cost is increased by about 1.3M€