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Outcome of the first SPL collaboration meeting

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Summary

The first SPL collaboration meeting took place at CERN on December 11-12, 2008. The foreseen content of the established collaborations was reviewed and refined to avoid unnecessary duplication. Taking into account the CERN contribution and the support granted by the European Union in its 7th Framework Program, the achievable goals were compared to the needs for preparing a technical design report and a cost estimate by mid-2011, and to allow for a start of construction at the beginning of 2012. The main results of this analysis are described in the body of this paper. A proposal for the future mode of operation of the collaboration was discussed. Its basic principle is outlined.

Numerous technical subjects were addressed during working group sessions, leading to a list of questions. The complete summaries and recommendations of the Working Groups are detailed in the Appendixes written by the corresponding chair persons.

1. Introduction

After the approval by the CERN Council in December 2007 of the “New Initiatives” proposed by the management, the preparation for mid-2011 of a technical design report and cost estimate of the SPL became an official activity. The additional resources and external contributions which were searched for during the previous years were hence converted into contracts involving international partners and their funding agencies. The main purposes of the first SPL collaboration meeting [1] were to clarify the foreseen content of the established collaborations and to identify the uncovered subjects. The most important conclusions are listed in the following sections.

The detailed meeting goals and the definition of the working groups are shown in Appendix A. The timetable is given in Appendix B. The list of participants (47) is in Appendix C.

The complete summaries and recommendations of the Working Groups are attached in Appendixes D, E, F and G

2. Main conclusions

The outcome of the meeting with respect to its goals is outlined in the following sections. More details are available in Appendixes D,E,F and G.

2.1 Review of specifications and technical choices – Deadlines for decision on pending questions

The frequency (704 MHz) and the cooling temperature (2K) decided after the assessment conducted last year [2] are not contested. The gradients of 25 MV/m (β=1) and 19 MV/m (β=0.65) are considered as challenging, but achievable with a reasonable yield provided the proper actions are taken (see section 2.3).

Moreover, it is recommended:

- to use a geometric β of 1 in the high energy cavities,
- to foresee HOM dampers, although Q_{ext} remains to be specified,
- to use klystrons with the highest power rating to drive multiple cavities,
- to foresee the use of vector modulators for each cavity.

Most of these recommendations deserve further study before implementation.

2.2 Definition of contributions

The external contributions which are presently approved with signed contracts are briefly summarised in Table 1. The contributions which are being negotiated are listed in Table 2.

Table 1: Summary of agreed external contributions

Institute	**Responsible person**	**Description of contribution**
CEA – Saclay (F)	S. Chel	• Design & construction of 2 β=1 cavities (EuCARD task 10.2.2) • Helium vessels for 2 cavities & tools for cryomodule assembly (French in-kind contribution) • Test of existing β=0.5 cavity in pulsed mode and participation to LLRF design (CNI "SLHC") • Tuner and RF coupler existing designs
CNRS - IPN – Orsay (F)	P. Duthil	• Design & construction of 1 β=0.65 cavity (EuCARD task 10.2.1) • Design and construction of prototype cryomodule (French in-kind contribution)
ESS –S (Lund)	M. Lindroos	• Beam dynamics • RF developments
Cockcroft Institute (UK)	A. Dexter D. Angal-Kalinin	• Participation to RF system specification and design • Study of RF components (RF power distribution, vector modulators, phase-locked magnetrons) • Study /design of low power collimators

Table 2: Contributions in negotiation

Institute	**Responsible person**	**Description of contribution**
ESS - Bilbao (SP)	?	- Design and construction of 50 Hz klystron modulator
ESS – Debrecen (H)	?	-
Rostock University (D)	H.W. Glock	- HOM damper design / analysis
Soltan Institute (PL)	S. Wronka	- Study /design of high power collimators
Stony Brook – BNL (USA)	I. Ben-Zvi	- Design and construction of prototype(s) β=1 cavity(ies)
TEMF Darmstadt (D)	?	- Study effect on beam of RF power couplers
TRIUMF (CA)	R. Laxdal R. Baartman	- Design and construction of prototype(s) β=0.65 cavity (ies) - HOM damper specifications

2.3 How to demonstrate 25 MV/m (β=1) and 19 MV/m (β=0.65) by mid-2011?

The foreseen gradients are considered as challenging, but achievable with a reasonable yield provided the proper actions are taken:

- State-of-the-art preparation of the cavities using the recipe established e.g. for the XFEL, including electro-polishing.

- Construction of at least 8 (2 x 4), preferably 12 (3 x 4) β=1 cavities. This gives a critical importance to the proposed US contribution. The results of a project carried forward by a partnership of a US National Laboratory and an industrial enterprise, Advanced Energy Systems, has been a demonstration of a 5-cell, 704 MHz SRF cavity. The design and performance of this cavity come very close to the SPL specifications in measured gradient and HOM requirements. This technological development, with some minor modifications, can be the basis for the construction of SPL cavities and auxiliary equipment.. In addition, it is highly recommended that CERN processes and measures cavities (>4). Increasing the number of cavities constructed by CEA from 2 to 4 is also highly desirable to improve confidence in the results.

- Construction of more than the single β=0.65 presently planned by IN2P3-Orsay (F). The Canadian proposal to build such cavities which is currently being negotiated would greatly increase the confidence in the measured results.

- Assembly of a full size cryomodule furbished with 8 β=1 cavities for analysis of collective performance. As a back-up solution, only one cavity can be equipped for pulsed operation at high power, while the others may operate at high Q and low RF power.

2.4 Untreated subjects and how to address them?

Some issues and suggestions/recommendations have already been treated in the previous sections. The complete list is summarised in Table 3.

Table 3: Untreated subjects and suggested actions

Need	**Recommended action**	**Recommended main contributor(s)**
High power RF test stand for cryomodule	Upgrade SM18 test place at CERN	• CERN (infrastructure) • ESS-Bilbao (Modulator)
Cost comparison of options for RF power distribution to cavities	Study & discuss	• CERN (study) • All partners (discussion)
Test an adequate quantity of cavities (~ 12 β=1 + 2-4 β=0.65) and prepare 8 β=1 cavities for installation in full-size cryostat	Build and test more cavities	• Stony Brook – BNL – AES (β=1) • TRIUMF (β=0.65) • CERN (β=1)
Adapt CEA designs for RF coupler and tuner to the SPL	Study / build / test devices and their integration	• ?
HOM dampers	Design / build / test devices and their integration	• ?
Define longitudinal layout of the SPL (lattice including beam instrumentation and extraction devices)	Design	• CERN

2.5 Organization of the collaboration

The SPL study relies extensively on external partners who hence have a crucial responsibility in its success (e.g.: for the time being all prototypes of superconducting cavities are being designed, built and tested outside CERN). It is therefore proposed to create a Collaboration Board (CB) where all partners will be represented and which will be regularly informed of the overall progress of the SPL study. The members of this board will be in charge of reporting to their home institute and of helping to find solutions in case of difficulties.

The rules of the collaboration, including the mode of operation of the Collaboration Board, will be stated in an MoU which will be submitted for signature to all partners.

2.6 Main meetings in 2009

The collaboration will briefly meet after PAC09 (May 4-8, 2009 – Vancouver) [3] and immediately before or after SRF09 (September 20-25, 2009 – Berlin) [4].

In addition, all collaboration members will be encouraged to participate to an exhaustive review of the status of the SPL study that will be organized at CERN during the last quarter of 2009. If established at that time, the Collaboration Board could meet immediately afterwards.

References

[1] http://indico.cern.ch/conferenceDisplay.py?confId=44821

[2] Assessment of the basic parameters of the CERN SPL, O. Brunner et al., CERN-AB-2008-067-BI-RF

[3] http://www.triumf.info/hosted/PAC09/

[4] http://www.helmholtz-berlin.de/events/srf2009/

Appendix A: Meeting goals and working groups

MEETING GOALS:

- to review specifications and technical choices and to set deadlines for decision on pending questions,
- to define the precise contribution of each partner (deliverables and planning) and the interactions between partners (names of persons in charge, exchange of information/hardware, planning of meetings, …),
- to propose how to demonstrate 25 MV/m (β =1) and 19 MV/m (β =0.65) before mid-2011
- to list untreated subjects and collect suggestions for addressing them,
- to organize the collaboration (Constitution?),
- to define the dates of the main meetings until end of 2009.

WORKING GROUPS

The mandate of the working groups is to fulfil the meeting goals on a subset of subjects.

WG 1 (conveners: E. Ciapala, A. Dexter): High power RF equipment (RF distrib., amplitude/phase modulators, circulators, loads...)
WG 2: (conveners: S. Chel, W. Weingarten): Cavity design (Geometric beta, high power coupler, HOM damper/coupler, tuner...) and construction (Manufacturers, processing facilities, low power RF tests...)
WG 3 (conveners: P. Duthil, V. Parma): Cryomodule and integration (Design, construction, assembly...)
WG 4 (conveners: R. Baartman, F. Gerigk): Beam dynamics and loss management (Collective effects, H- stripping, collimation...)

Appendix B: Timetable of the first SPL collaboration meeting

Thursday 11, December 2008

Plenary session 1: Introduction
09:00 Welcome – L. Evans
09:10 SPL study and meeting goals – R. Garoby
09:30 SPL specifications and design choices – F. Gerigk

Plenary session 2: Planned contributions to the SPL
10:20 CEA (Saclay) plans – S. Chel
10:40 IN2P3 (Orsay) plans – P. Duthil
11:00 TRIUMF plans – R. Laxdal, R. Baartman
11:20 Cockcroft Institute plans – A. Dexter
11:40 Stony Brook / BNL plans – R. B. R. Calaga, I. Ben-Zvi
12:00 Explanation/Discussion on the mandates of the working groups – R. Garoby

Working Groups - Session 1

- **WG 1 and 4**

14:00 RF Power Distribution for SPL - Introduction – E. Ciapala
14:15 RF Power Distribution = System Layout and Components – D. Valuch
14:45 Cockcroft Institute - HP RF Expertise and Areas of Interest – A. Dexter

- **WG 2**

14:00 On the optimum choice of the geometric beta of the sc cavities – F. Gerigk
14:15 Discussion on cavity beta and other design issues
14:30 Do we need HOM dampers on SC cavities in p linacs? – J. Tuckmantel
14:50 HOM studies for TESLA – H. W. Glock
15:10 HOM damping on sc cavities – J. Tuckmantel
15:30 Discussion HOM coupler

- **WG 3**

14:00 Introduction to the meeting
14:15 Contribution from CNRS (France)
14:35 Discussion

Working Groups - Session 2

- **WG 1**

16:00 Klystron Modulators for the LP-SPL and for the HP-SPL – C. De Almeida Martins
16:40 Review of Specifications and Technical Choices - Part 1 – E. Ciapala
17:20 Review of System Specifications and technical choices - Part 2

- **WG 2**

16:00 Processing of cavity to obtain design performance – S. Calatroni
16:20 RF test of individual cavities – P. Maesen
16:40 Discussion session

- **WG 3**

16:00 Possible quadrupole solutions – D. Tommasini
16:20 Discussion

- **WG 4**

16:00 Beam dynamics in the SPL – M. Eshraqi
16:15 Discussion on beam dynamics in the SPL
16:30 H- beam splitting for EURISOL targets – M. Lindroos

16:45 Discussion on H- beam splitting for EURISOL
17:00 Discussion: impact of cavity performance on beam dynamics
17:15 Discussion: H- stripping in transfer line via blackbody radiation
16:20 Discussion

Friday 12, December 2008

Plenary session 3: Discussion
08:30 Organization of the collaboration (with discussion) – R. Garoby
09:00 Preliminary feedback from the Working Groups

Working Groups - Session 3

- **WG 1, 2 and 3**

11:00 Assembly and test of fully equipped cryomodule – P. Maesen
11:15 High power RF coupler - CEA-Saclay experience – G. Devanz
11:30 High power RF coupler - CERN experience – E. Montesinos
11:45 On the choice of the frequency tuner – G. Devanz
12:00 Discussion on addressed topics and on integration issues between WG1, 2 and 3

- **WG 4**

11:00 Collimation for Linac4 – J. Fernandez-Hernando
11:15 Discussion on collimation for Linac4
11:30 Collimation and radiation protection, experience at the Soltan Institute – S. Wronka
11:45 Discussion on collimation/radiation studies at the Soltan institute
12:00 Discussion on task splitting between Cockroft and Soltan Institute
12:15 Discussion: longitudinal momentum collimation

Write-up of summary and recommendations of the Working Groups
14:00 till 15:45

Plenary session 4: Summaries and recommendations
16:00 Working Group 1 – E. Ciapala, A. Dexter
16:20 Working Group 2 – S. Chel, W. Weingarten
16:40 Working Group 3 – P. Duthil, V. Parma
17:00 Working Group 4 – R. Baartman, F. Gerigk
17:20 Summary on organization and planning of the collaboration – R. Garoby

Appendix C: Participants

APOLLINARI, Giorgio	FNAL	USA
BAARTMAN, Rick	TRIUMF	Canada
BAUDRENGHIEN, Philippe	CERN	
BEN-ZVI, Ilan	University Stony Brook, BNL	USA
BERMEJO, Francisco Javier	ESS – Bilbao	Spain
BRUNNER, olivier	CERN	
CALAGA, Rama	BNL	USA
CALATRONI, Sergio	CERN	
CARRERA, Miguel Angel	ESS – Bilbao	Spain
Catalan Lasheras, Nuria	CERN	
CHEL, Stephane	CEA	France
CHIGGIATO, Paolo	CERN	
CIAPALA, Edmond	CERN	
DEVANZ, Guillaume	CEA	France
DEXTER, Amos	Lancaster Uni., Cockroft Institute	UK
DUPERRIER, Romuald	CEA	France
DUTHIL, Patxi	CNRS-IN2P3	France
EGUíA, Josu	ESS – Bilbao	Spain
ENPARANTZA, Rafael	ESS – Bilbao	Spain
ERIC, Montesinos	CERN	
ESHRAQI, Mohammad	CERN	
FERNANDEZ-HERNANDO, Juan Luis	STFC	UK
FERREIRA, Leonel	CERN	
GANUZA, DANIEL	ESS – Bilbao	Spain
GAROBY, Roland	CERN	
GERIGK, Frank	CERN	
GLOCK, Hans-Walter	Rostock University	Germany
HOFLE, Wolfgang	CERN	
LARRAñAGA, Mikel	ESS – Bilbao	Spain
LAXDAL, Robert	TRIUMF	Canada
LINDROOS, Mats	CERN, ESS-S (Lund)	
MAESEN Pierre	CERN	
Olry Guillaume	CNRS-IN2P3	France
PARMA Vittorio	CERN	
PEGGS, Steve	ESS-S (Lund)	Sweden
PEREZ, ALBERTO	ESS - Bilbao	Spain
SAUGNAC, Hervé	CNRS-IN2P3	France
SCHUH, Marcel	CERN	
STER, András	ESS-Hungary	Hungary
STRAIT, James	FNAL	USA
TOMMASINI, Davide	CERN	
TUCKMANTEL, Joachim	CERN	
URIARTE, Luis	ESS - Bilbao	Spain
VALUCH, Daniel	CERN	
VRETENAR Maurizio	CERN	
WEINGARTEN, Wolfgang	CERN	
WEISZ, Sylvain	CERN	
WRONKA, Slawomir	Soltan Institute	Poland

Appendix D: WG 1 (High Power RF) summary – E. Ciapala, A. Dexter

SPL beam specifications

		LP-SPL	HP-SPL	HP-SPL
	Application	**LHC**	**ν factory**	**EURISOL + ν factory**
A	Kinetic Energy	4.0 GeV	5.0 GeV	2.5 and 5.0 GeV
B	Rep.-period	600 ms	20 ms	20 ms
	Protons/pulse	1.5e14	1.5e14	2e14 (2.5 GeV) + 1e14 (5 GeV)
C	Average pulse current	20 mA	20 mA	40 mA
D	Pulse duration	1.2 ms	1.2 ms	0.8 ms (2.5 GeV) + 0.4 (5 GeV)
	Beam power (A*C*D/B)	0.16 MW	6.0 MW	8.0 MW

Acceleration from 180 MeV to 643 MeV with 42 β = 0.65 superconducting cavities
Acceleration from 643 MeV to 5000 MeV using 200 β = 0.92[1] superconducting cavities.

Cavities

Beta	0.65	0.92[1]
Frequency	704.4 MHz	704.4 MHz
Cells per cavity	5	5
Gradient	18.7 MV/m	24 MV/m
Cavities per cryomodule	6	8
Total cavities	42	200
Kick per cavity	11.0 MeV	22.0 MeV
Pulsed beam-loading per cavity (20 mA beam)	220 kW	440 kW
Pulsed beam-loading per cavity (40 mA beam)	440 kW	880 kW
Average power in coupler (50 Hz, 40 mA)	26 kW	52 kW

Klystrons

CPI builds 1MW, 704 MHz Klystrons (1 is available at Saclay and 1 at BNL).
For a single beam Klystron the maximum available power at 704 MHz and 10% duty cycle is about 5 MW but no "off the shelf" Klystron exists. A 5 MW Klystron was developed for the SNS at Oak Ridge which operates at 805 MHz.
Assuming 4-5 MW Klystrons costing 500 k€ each, the number of cavities they can drive, their total inventory and the total cost are given in the following table.

Maximum number of cavities per Klystron / (peak power no loss)	I beam = 20 mA	I beam = 40 mA
β = 0.65	12 (2.64 MW)	6 (2.64 MW)
β = 0.92[1]	8 (3.52 MW)	4 (3.52 MW)
Total Klystrons	4 + 25 = 29	7 + 50 = 57
Nominal cost not including modulators	14.5 M€	28.5 M€

Using one Klystron to drive many cavities would drastically simplify the high power RF distribution and the control of the field in the cavities. However, from the economical point of view, using a single 1 MW klystron per cavity and estimating a unit cost of 300 k€, brings the

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[1] During the meeting the decision of adopting β=1 was not taken; WG 1 used the data published in ref. [2]

total cost to ~ 72.6 M€ (to be compared to 28.5 M€ – case I beam = 40 mA). This becomes even more so if each klystron is equipped with its own high voltage modulator.

Precise control of RF phase and amplitude are specified – 0.5 % and 0.5 degrees respectively. This has to be obtained in the presence of a number of perturbing effects like:

- Lorentz detuning coupled with microphonics
- Individual tune variations due to cryogenics induced oscillations
- Variations in cavity forward power due to waveguide system reflections and beam induced signals

These can only be partly compensated via the fast piezo tuner. Fast feedback on the phase and amplitude of the RF supplied to each individual cavity is essential. If there is a klystron for every cavity this can be achieved easily with RF feedback. In the case of multiple cavities driven by a single klystron, RF feedback cannot counteract the individual cavity effects. The only way of providing the required stabilization is to have a fast vector modulator in front of each cavity, controlled by a feedback loop. In addition, individual adjustment of cavity phase and amplitude may be desirable for the tuning of the linac, particularly in the low beta section where the particles are non-relativistic and voltage errors can result in phase errors at subsequent cavities.

Fixed delay elements in the distribution systems are also certainly required to get the correct phase on each cavity, with the vector modulator working near mid-range.

A circulator in front of each cavity is essential to limit reflected power transmission to neighbouring cavities, particularly if a cavity has to be partly or completely detuned due to limitation in its maximum gradient.

Baseline Distribution Solution

Daniel Valuch (CERN) proposes the high power layout set out in figure D1 below, where one Klystron feeds several cavities and which encompasses high power vector modulation.

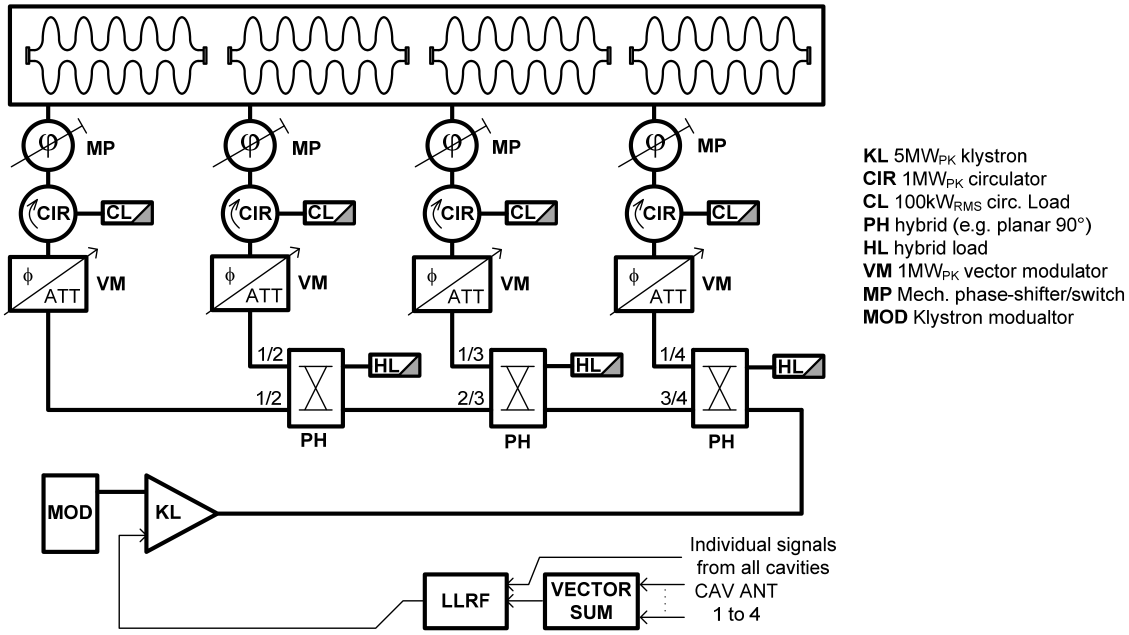

Figure D1: Proposed high power RF distribution

Comments

1. The solution of figure D1 gives the minimum waveguide length with respect to other possibilities.
2. The vector modulator is positioned before the circulator
3. Use of WG975 should be studied, rather than WR1150 as it is more compact, losses seem to be OK and will cut off 3rd harmonic modes with n>1 .
4. Power splitting is done with 90° Hybrid. Their coupling will be fixed during assembly by careful positioning of shunt posts and will not be remotely controllable (The simpler XFEL asymmetric shunt Tee was not chosen as it does not provide sufficient isolation).
5. Remote controlled limited variability of the splitting ratios from the 90^o Hybrids would be desirable.
6. High power vector modulators do not exist and an R&D program is needed to determine whether they are feasible.
7. Circulators at the proposed power level are available.
8. Mechanical phase shifters have less loss than variable phase shifters and hence should be used to remove static offsets. Design is straight forward.

Questions

1. What is the real cost difference between the one/several cavities per klystron configurations – taking into account:
    a. Klystron costs
    b. Modulator costs
    c. RF distribution system costs, including vector modulator design, development and fabrication
    d. Integration and space requirements, including civil engineering
    e. Operational flexibility and overall reliability
2. How well will the piezo tuners limit cavity de-tuning? (Ongoing “SLHC” CNI with tests at Saclay should provide an answer)
3. Specifications of the vector modulators (dynamic range and bandwidth/response time)? (Ongoing “SLHC” CNI should provide an answer)
4. Are vector modulators really necessary? Can they be suppressed or would phase shifters be enough? Note that the attenuation implicit with amplitude modulation carries a penalty in RF power... (Ongoing “SLHC” CNI should provide an answer)
5. Are there differences between LP and HP SPL with respect to the above?
6. Once questions 1-4 are answered, what will be the power overhead associated with de-tuning?
7. What will the distribution losses be for the system proposed and alternative systems and for the two possible waveguide sizes WG1150 and WG975?
8. Does the 3rd harmonic cut off for modes with n>1 provided by WG975 bring significant benefits over the use of WR1150. If Klystron harmonics might cause a problem should we be considering a filter?
9. Is there any potential for arcing and hence a requirement for SF6 with its associated constraints and infrastructure?

Possible Modifications

1. Phase shifters instead of vector modulators with a more complex LLRF system.
2. Drive each cavity with a phase locked magnetron. This gives individual control of each cavity at what is expected to be a lower cost than the 4 cavities per Klystron cost. It also eliminates the need for high power vector modulation and could be a fall back if high power vector modulation does not work.

R&D proposal

Cockcroft Collaboration interests

- Understand the phase and amplitude tolerances as a function of location in the Linac and complexity of the LLRF.
  (CI – CERN collaboration) suggest April 2009
- Determine a specification for the high power vector modulators and simpler phase shifters as a function of LLRF control system and beam power.
  (CI – CERN collaboration) suggest April 2009
- Studies of the overall HPRF system as the layout develops and characteristics of components become known. Consider inter-cavity coupling, losses, power equality, effect of reflections, beam induced signals etc. We would base this on a few selected topologies.
  (CI – CERN collaboration) suggest April 2010
- Determine the power overhead need by the control system to meet phase and amplitude tolerances in the presence of Lorentz detuning and microphonics.
  (Not enough is known to address this issue yet) suggest July 2011
- Develop and & demonstrate vector modulators at the highest power level and the 50Hz repetition
  (CI – CERN collaboration + UK industry?) suggest December 2010
- Klystron Review
  (CI) suggest September 2009
- Development of a long pulse Phase Locked Magnetron solution where one magnetron is used per cavity. Demonstrate feasibility at the 1 kW power level, develop a modulator design for high power operation, generate interest from a magnetron manufacturer to produce a 1 MW long pulse 704 MHz magnetron and perform a cost analysis. Seek further funding to complete high power development.
  (CI independent program initially)
- Develop a remote variable splitting technology.
  (lower priority CI activity) suggest December 2010

ESS Bilbao interest

- Design study and development of the Klystron Modulator for HPSPL. The 50 Hz modulator for the HP SPL is a new and very different device from that of the LPSPL. Upgrade probably means complete replacement. A collaboration with CERN, ESS Bilbao and industry should look at topology, specs and the design. Integration is also an important issue.
  (ESS Bilbao & CERN TE PO)

Essential CERN activities

- Costing of single klystron per cavity option, also considering integration issues.
- Integration and Layout of the various options. In particular layout of distribution system in the two tunnels, klystrons (vertical or horizontal) and modulator layout for HPSPL (See below) **- URGENT**
  (CERN)
- Test stand 704 MHz, 5 MW. Needed for HP tests of RF equipment, klystrons, waveguide proto layout, later for test of cryomodules then klystron modulator for HPSPL.
  (CERN)
- Development / construction of the LPSPL vector modulator for test stand.

Appendix E: WG 2 (Cavity design and construction) summary – S. Chel, W. Weingarten

On the geometrical β of high energy cavities

From considerations of the total length of the linac, **no imperative argument was found for building up the high energy SPL from cavities with a β different from 1**. Several arguments are in disfavour of a lower β. From considerations of the peak surface electric field or the peak surface magnetic field being the limiting field, the maximum gradient for $\beta = 0.92$ would be 3 or 7 % lower, respectively. In addition to that, the dissipated power, being inversely proportional to the shunt impedance, is supposed to be 20 % larger, which has to be confirmed[2].

On the electromagnetic computation of HOMs and their damping

In most of the recent work on $\beta < 1$ cavities, the power deposited inside the cavity was determined that is induced by HOMs at a harmonic frequency of the bunch repetition time with a longitudinal E field component. In addition to that, similar as in a circular accelerator, the bunch excites HOMs the frequency of which may not coincide with a machine line and may lead to beam break up. A threshold condition for beam breakup depends, amongst other parameters, upon **the required loaded Q of the HOM and needs to be figured out**. Computer codes as available at JLAB and SNS may be used for that purpose **(TRIUMF)**. A study performed at SNS showed a beneficial effect of a high loaded Q, an apparent contradiction to accepted practice, which should be better understood.

On cold tests of HOM couplers; HOM absorber vs. antenna coupler

Computer simulations of mode propagation inside cavities and between cavities have made large progress in recent years, thanks to new theoretical models. The experience gained for XFEL may be beneficially extended to the SPL. In addition, the damping action provided by HOM couplers may be successfully simulated by these codes **(Uni. Rostock)**[i]. To test these simulations on a warm model cavity is not really worthwhile; **they should be performed on a cold cavity (CERN), preferentially at larger gradients than nominal.** HOM absorbers in or close to the beam tubes, potentially easier to install, are being developed, may be cooled by lN_2, but have to cope with tolerable power dissipation into the helium bath. HOM antenna dampers, more difficult to design and assemble, are mature and allow a safe evacuation of the HOM power to a room temperature load, provided they are actively cooled. They may in addition be used for beam diagnosis. Both options may provide viable technical solutions. **The HOM antenna damper can be used as designed at present.**

On how to convincingly demonstrate a nominal gradient of 25 MV/m (β =1 cavities) on a cryo-module

The gradient of 25 MV/m is considered as possible to achieve, however at the upper end of present technology. A lower gradient would lead to an increase in length of the SPL, resulting in larger investment costs. **Unanimous agreement was on the necessity of applying the standard recipe, close to what is established for the XFEL or KEK, including electro-polishing.** As the electro-polishing equipment is concerned, however, it will be made available at **CEA - Saclay** (by means of the EuCard programme) as of about 2010, which is late for the demonstrator cryo-module due for mid 2011. **It is therefore mandatory that such equipment**

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[2] It was meanwhile shown that the difference in power consumption is insignificant (private communication from F. Gerigk, M. Eshraqi, M. Schuh)

be built up (CERN) fast and that, to bridge the time gap before completion, industry (ACCEL, HENKEL) may be involved.

As to the number of cavities to be manufactured and processed, the spectrum of opinions was broad. However, in view of the technological challenge of the SPL project, a number of cavities not lower than 8 was proposed that should comply with the specification (i. e. E_a = 25 MV/m inside a cryo-module). Preferentially this batch of 8 cavities should be processed at the same place within a relatively short period according to a predefined and agreed protocol (that of XFEL). If needed, the processing might be split onto 2 or 3 premises, with 4 cavities each **(BNL and/or CEA - Saclay and CERN)**.

Manufacturing capacities were identified as sufficient, being located in **BNL** (AES), **TRIUMF** (Pavac), **CEA - Saclay**, **CERN, ESS** (Bilbao, Spain) and **Soltan Institute** (close to Warsaw, Poland).

The issue on diagnosis equipment (on-line, or off-line) was also addressed. In view of the restricted time until the test of the demonstrator cryo-module, the manufacture of a complete T-mapping system was considered as unrealistic. However, **relatively light compensatory quench diagnosis systems, such as T-mapping of the cell identified as faulty, or a second sound quench location system, or a Questar like optical system, should be rapidly assessed and subsequently set up (CERN).**

The most complete demonstrator consists of a fully equipped cryo-module with 8 cavities, focusing elements, and the required ancillary equipment, such as fast and slow tuners, power couplers and HOM couplers (if needed), tested at the nominal inclination of the ground level under high RF power (1 MW per cavity) by mid 2011.

The next less ambitious, but still meaningful demonstrator version could consist of a similar cryo-module, but with only one cavity fully equipped **(summer 2011)**, the other cavities having only low power couplers and possibly no HOM dampers. All cavities could still be pulsed simultaneously at full gradient, using long pulses and a very slow cycling rate. This option would allow demonstrating a sufficient number of cavities with nominal performance, being a statistical issue, and also the correct functioning of the ancillary elements, proving their sound design.

Any other more downgraded setups are considered less meaningful.

More data on the statistical performance of SPL type cavities will be provided by the TRIUMF - INP - Orsay collaborative effort to have β = 0.65 cavities produced in industry.

On how to assemble and test a fully or partially equipped cryo-module

For assembling the full cryo-module, a 15 m long - class 10 - rail-equipped clean room is needed. Such a clean room is available at **CERN - SM18**, in close vicinity of the cold test area; the class 10 online monitoring equipment needs to be refurbished. A clean room of similar size and performance is under construction at **CEA - Saclay** ; it should be intensively exploited until end of 2012 for the needs of other projects (SPIRAL2 and XFEL). The assembly procedure as applied now for the LHC cryo-modules is different from usual practice for the high gradient structures, as used in XFEL and FLASH (DESY), and should be re-assessed.

As came out of the study on frequency and temperature, the SPL cryo-module is operated at a bath temperature of 2 K. Hence the test of the demonstrator must be performed under similar conditions at CERN, with high RF power.

The SM18 test place, consisting of 4 vertical cryostats and 2 horizontal bunkers of 15 m length each, is designed for 4.5 K operation under steady state conditions and low RF power, with the possibility to cool down to 2 K without simultaneous replenishment. In addition, the heat losses in the lHe transfer lines are relatively large. **Hence the SM18 cryogenic installation must be refurbished, the bunkers possibly extended in length, and the RF power station must be upgraded to comply with the power needs of the fully assembled SPL cryo-module (CERN, spring 2011).**

The 704 MHz high power RF equipment could replace the present 352 MHz equipment in use for the LINAC 4, which may be moved elsewhere as of 2011.

With regard to the vertical tests, the SM18 cryogenic test zone is being extended to 704 MHz low power capability.

On ancillary equipment

Power coupler: In the HIPPI activity, a 704 MHz high power coupler for 1 MW pulse operation was developed, which is to be tested very soon at CEA Saclay. It is a coaxial antenna type coupler with a single room temperature window. However, the mechanical design has to be adapted to the SPL cavity and cryo-module.

BNL is peparing a dual power coupler (2 x 0.5 MW CW in opposite position) to be tested soon. The impact of a single or dual coupler on the beam should be studied **(TEMF Darmstadt)**[3]. First field calculations are available at BNL and may be used for benchmarking.

A large experience on power coupler conditioning and interlocking is available at CERN (the LHC power coupler was operated up to 575 kW in full reflection).

In all design considerations, priority is attributed to the requirements of the high power SPL.

Frequency tuner: The Saclay combined slow/fast frequency tuner also developed under HIPPI may be modified for the SPL. It is being successfully operated in FLASH, though under less demanding conditions. Therefore it should be repetitively tested with a cycle number typical of the lifetime of SPL.

BNL is also preparing a tuner test, the results of which will be available soon.

The power coupler and frequency tuner for SPL should be based on the previously described prototypes as produced at CEA - Saclay. The supplier must be defined rather soon **(spring 2009)**.

Magnetic shielding: The cavity should not be exposed during cool-down to a static magnetic field exceeding about 1 µT. Several solutions are presently used (i.e. a double shield outside and inside the cryostat, or a single shield inside the cryostat) and must be integrated into the design of the cryostat.

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[3] to be confirmed (on condition that the German University's request to the German Ministry of Education and Research BMBF for financing accelerator related research is approved).

Appendix F: WG 3 (Cryomodule design and integration) summary – P. Duthil, V. Parma

Understand limits of scope of CEA and CNRS contributions

The French institutes will contribute to the development of the cryomodules in the frame of a collaboration agreement which is being agreed as part of the special contribution of France to CERN.

The contribution from CNRS covers 2 work packages: a first one for the general design of cryostat components, integration study of internal sub-systems and procurement of cryostat components for one prototype cryomodule; and a second one for the design and procurement of the supporting and guiding system of the string of cavities in the cryostat. There is a general agreement on the limits of the scope of CNRS's contribution, though a number of conceptual issues and boundary conditions still need to be clarified and settled before the design work can start. In particular, a functional specification setting design objectives should be prepared. The integration study will require that a number of interfaces with the components and/or systems to be integrated are settled, but in a number of cases it is premature. Interface specifications will have to be set-up to define clear limits for integration.

The level of the contribution from CEA could not be assessed as the people from CEA were essentially devoted to the work in the other working groups. In principle, CEA is committed to participate through 2 work packages: a first one for the design and procurement of 2 helium vessels, and a second one for the design and procurement of the cryostat assembly tooling. Both activities are strongly linked to the cryostat design activity and will need close communication between CEA and CNRS.

Recommendations: Further discuss with CEA and formalize collaboration agreement.

Identification of integration needs: components type, interfaces, functional needs.

Most components were identified, but their level of functional needs and interfaces in the cryomodule needs to be clarified. As an example, cooling needs of components like the HOM, are still unclear and very much dependent from the type of solution which is chosen.

Recommendations: set-up a Product Break-down Structure (PBS) and interface specifications.

Identification of uncovered items and conceptual design of sub-systems

These are still some essential components for which the design choice is unclear. The type of HOM or the magnetic shielding still need to be defined. The CEA solutions for coupler and tuner seem to be the most appropriate but need to be engineered for the specific needs of SPL. The potential interests shown by the institutes in contributing with these essential components should be formalized at the soonest in order to proceed with the design of the cryomodule and make them available in time for the prototype.

Recommendations: clarify type of components to be used and commitment for contributions.

Define list of topics towards a functional specification: alignment requirements, thermal budgets (static+dynamic), mechanical requirements

Most of them were addressed but functionalities and specifications need to be critically addressed and settled. For example, the alignment requirements for the quadrupoles and cavities should be differentiated in order to design the supporting systems and methodology for the assembly, or temperature levels of cooling heat interception on components should be clarified to define the non-isothermal cooling profiles along the cryomodules. Clearly, this will have to be the result of an iterative process between persons in charge of cryo-module and of sub-systems.

Recommendations: Produce and approve a functional specification for the cryomodules.

Define input for mechanical layouts, cryogenics specs (pressures & temperatures)

Discussions around these points raised a number of relevant new issues.

Length of the continuous SPL cryostat. Despite the initial understanding that the longitudinal layout of the SPL cryomodules could be continuous over the total length if about 500 m, it appears that warm sections may be required to integrate beam diagnostics which cannot operate at cold inside the cryostats. This would require Cold-to-Warm transition zones and by-pass transfer lines for feeding cryogenic lines over the warm zones. These transitions will condition the design of the cryomodule in terms of cryogenic pipe sizes and cross sectional positioning inside the cryostats, as well as have an impact on the length of the SPL and on its tunnel integration.

Beam vacuum sectorization valves. Removal of one cryomodule from the SPL should be possible for maintenance reasons. Not to hinder the cleanliness of the cavities in the adjacent cryomodules, sectorization valves should be present at each interconnection and could be manually closed before removing the cryomodule. Possible fast interlocked closing could be necessary to avoid pollution of cavities in case of accidental break of vacuum.

The external supporting system of the cryomodules to ground needs to be addressed. It seems that a floor supported system like for the LHC and ILC would be preferable but this issue should be analyzed including interface needs of the power couplers/wave guide systems as well as tunnel integration.

The operating temperature of ~2K is assumed as the baseline, but if operation at 4.5K is also foreseen (as occurred for initial operation at SNS), this would require some design precautions in the helium envelope to avoid trapped vapors which would limit cooling of the cavities surface.

The tunnel slope (1.7%) will certainly affect the cryogenics operation and the control scheme to be adopted, and this will lead to the required control instrumentation to be integrated in the cryomodules. In no case the experts consider that the slope may hinder cryogenic operation if appropriately studied.

The Helium Gas Return Pipe (HeGRP) will require a large diameter (~300mm) if designed for the HPSPL version, and in this case it would make sense to use this pipe as mechanical backbone for the cavities, as for Tesla cryomodules.

The design pressure of the cavities in the helium vessels and operation pressure stability were not addressed and should be agreed with the cavity experts, as these parameters may be limiting the cool-down pressure of the cryomodule and affecting cavity tuning respectively.

Recommendations: 1) set up a baseline for the longitudinal layout of the SPL including the machine lattice, beam diagnostics, and elaborate, based on it, the mechanical layouts of the main machine systems (cryogenics, vacuum, powering) related to the cryomodules. 2) Learn from the experience of XFEL. 3) Produce and approve a cryogenic specification for temperatures and pressures in the cryomodules.

Quadrupole magnets and powering schemes.

The required field gradients do not seem to be too demanding at this stage and a number of technical solutions could be adopted, ranging from permanent magnets to current or iron dominated superconducting magnets. The magnets can be quite compact. The field gradients required along the SPL, the needs for individual or clustered powering or tuning still need to be specified and these will have an impact on the design and integration of the cryomodules (local powering?, common powering in series?). Also, the fringe fields acceptance for the cavities (<10 milligauss, TBC) may define minimum distance, need for shielding or compensated magnets.

Recommendations: set up a baseline specification for the quads lattice.

Elaborate a work organization structure; planning issues.

It is felt that the best way to coordinate the design of the SPL cryomodules is by having a dedicated technical working group with identified representatives from all the engineering systems concerned (cryogenics, vacuum, cavities, magnets, RF powering, alignment, instrumentation,…), and with at least one representative per participating institute. Regular meetings (monthly?), for which a list of participants may be defined based on the topics discussed, would lead the design of the cryomodules for the SPL and eventually evolve towards a project meeting for the construction of the first prototype cryomodule. It was stressed that the aim of construction and assembly of a first cryomodule prototype by the 3rd quarter of 2011 is ambitious and leaves only 1 year (2009) to complete the design.

Recommendations: set-up of a cryomodule design working group steered by CERN.

Appendix G: WG 4 (Beam dynamics) summary – R. Baartman, F. Gerigk

Do we need HOM dampers on superconducting cavities in proton linacs?

We conclude that it is difficult to foresee all effects that can be driven by Higher Order Modes (HOM). J. Tuckmantel showed how an HOM can interact with the beam even if its frequency is not a multiple of the beam frequency. Furthermore HOMs can "connect" the cavities of one cryo-module such that the fields of one cavity influence the fields of neighbouring cavities. While it is true that HOM couplers add a certain complexity and cost to a project we consider that:

- They can work reliably without adding risks for operation (see experience with LEP, LHC couplers). However, they need a sufficient amount of R&D to achieve this reliability, especially for operation at high duty cycles as foreseen for the SPL.
- The actual cost of HOM couplers seems small compared with the potential risk for operation that arises when omitting HOM damping completely.
- There seems to be a possibility that they can be used as Beam Position Monitors (BPMs), which could save the cost (and real estate length) of traditional BPMs in the beam line.

The amount of required damping (Q_{ex}) will be studied by TRIUMF (BBU) until mid-2009.

We recommend to use HOM couplers for the SPL and to start with the design as soon as there are first numbers for the required Q_{ex}.

Collimation needs in Linac4/SPL?

There were two introductory talks by J. Fernandez-Hernando (STFC) and S. Wronka (Soltan Institute) on collimation. During the discussion possible locations for transverse and longitudinal collimators were identified as depicted in Fig. 1. The potential 3 locations for transverse collimation are: i) within Linac4 (between different accelerating sections), ii) after Linac4, iii) at the moment when the transfer line changes its slope to horizontal. Longitudinal collimation could be done after the SPL either i) at the first change in vertical slope, or ii) at the point where the transfer line becomes horizontal again.

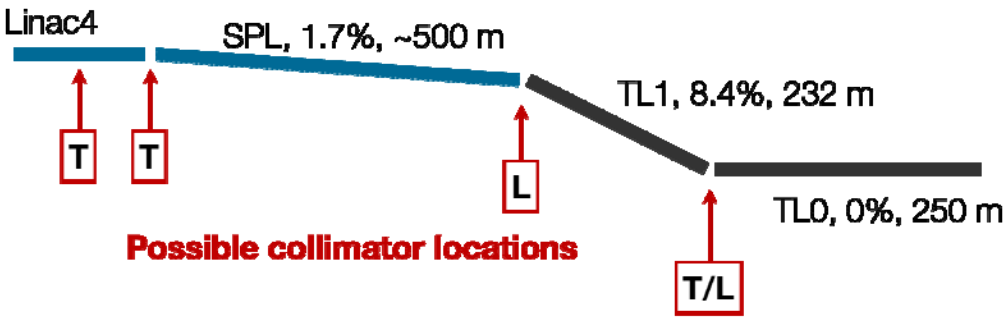

Figure 1: Possible collimator locations for transverse (T) or longitudinal (L) collimation.

Transverse collimation within or after Linac4 is under study by STFC, where work has already begun. STFC is studying low-power collimators (10, 20, 50 W) for use in Linac4 (50, 100, 160 MeV), while the Soltan Institute is looking at higher power collimators (10, 100, 1000 W, beam power to be specified by CERN error studies) in the transfer line between SPL and the injection into PS2. During the discussion it was recommended to use shielded carbon collimators for Linac4, while the material choice for the SPL is still open. STFC will also study with beam dynamics simulations whether it is possible to do longitudinal collimation at the proposed locations. The proposed method for longitudinal collimation is stripping of the transverse halo in/after the bending magnets and to divert these particles to dedicated dump areas. The deadline for this work is mid-2009. The Soltan institute will study transverse collimators for use in the SPL and will be closely involved in radiation protection studies for the SPL. The deadline for Linac4/SPL collimator proposals is end of 2009. A detailed work package description has been sent to both institutes.

The Soltan Institute will send a collaborator to CERN for a period of 2-4 months so that (s)he can be trained in the CERN standards for radiation safety and integrated in the relevant CERN groups. STFC is also considering a CERN visit (2 or more weeks) to work more closely with the collimation experts at CERN.

Open subjects?

Subjects that are not yet covered are:

- Beam distribution to EURISOL targets (see presentation by M. Lindroos). It was said that this work may be done in the framework of EURISOL.
- The general beam dynamics layout of the SPL, the definition of quadrupole specifications and the general design of the transfer line will be studied at CERN with support from ESS-S (European Spallation Source, Swedish/Scandinavian initiative).
- The impact of cavity performance on the linac dynamics (failing cavities, gradient spread) is not yet covered.
- It is recommended to re-evaluate the physics model of H- stripping via black-body radiation in the transfer line. For the time being the subject is not covered.
- Alignment precision for cavities, magnets and BPM needs to be defined.
- The required diagnostics elements need to be defined with high priority.
