Status & plans of the SPL* study at CERN

1. Introduction
2. SPL principle and characteristics
3. On-going R&D
4. Staging
5. Summary and Conclusion

*** SPL = Superconducting Proton Linac**

A concept for improving the performance of the protons beams at CERN, ultimately based on a high-energy Superconducting Linear Accelerator

The SPL Working Group

B. Autin, A. Blondel, **K. Bongardt**[1], O. Brunner, R. Cappi, **F. Caspers**, E. Cennini, **E. Chiaveri**, S. Claudet, **H. Frischholz**, R. Garoby, **F. Gerigk**[4], K. Hanke, H. Haseroth, C. Hill, N. Hilleret, I. Hoffman[2], J. Inigo-Golfin, M. Jimenez, A. Krusche, D. Kuchler, M. Lindroos, **A. Lombardi**, R. Nunes, **R. Losito**, **M. Paoluzzi**, J. Pedersen, M. Poehler, H. Ravn, A. Rohlev[3], R.D. Ryne[3], M. Sanmarti, H. Schönauer, **M. Silari**, **J. Tuckmantel**, H. Vincke, A. Vital, C. Vollinger, **M. Vretenar**

[1] KFZ Juelich, Germany
[2] GSI - Gesellschaft für Schwerionenforschung, Germany
[3] LANL - Los Alamos National Laboratory, USA
[4] RAL , Oxford, England
others are from CERN, Switzerland

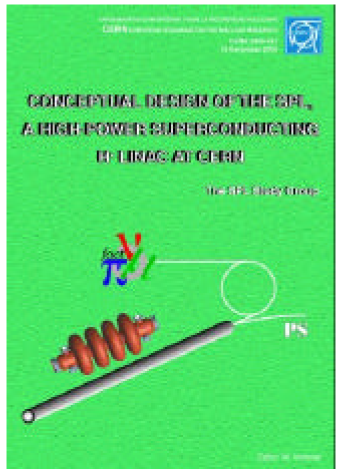
COLLABORATIONS

CEA (DSM/DAPNIA @ Saclay) + CNRS (IN2P3 @ Orsay & Grenoble): RFQ + DTL (IPHI)
INFN (Legnaro): R FQ
ITEP (Moscow): Room Temperature option between 120 – 240 MeV

REFERENCES

- Conceptual Design of the SPL, a High Power Superconducting Proton Linac at CERN Ed. M. Vretenar, CERN 2000-012

- SPL web site: http://cern.web.cern.ch/CERN/Divisions/PS/SPL_SG/

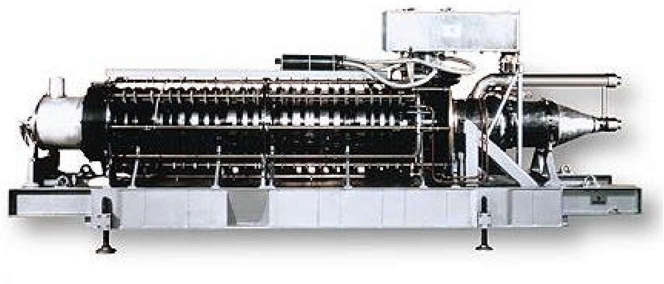


Applications and Benefits

- **Approved physics experiments**
  - CERN Neutrinos to Gran Sasso (CNGS): increased flux (~ $\times$ 2)
  - Anti-proton Decelerator: increased flux
  - Neutrons Time Of Flight (TOF) experiments: increased flux
  - ISOLDE: increased flux, higher duty factor, multiple energies
  - LHC: faster filling time, increased operational margin
- **Future potential users**
  - LHC performance upgrade beyond ultimate
  - “Conventional” neutrino beam from the SPL “super-beam”
  - Second generation ISOLDE facility (“EURISOL” -like)
  - Neutrino source from “beta beams”
  - Neutrino Factory

The Superconducting Proton Linac: Main Principles

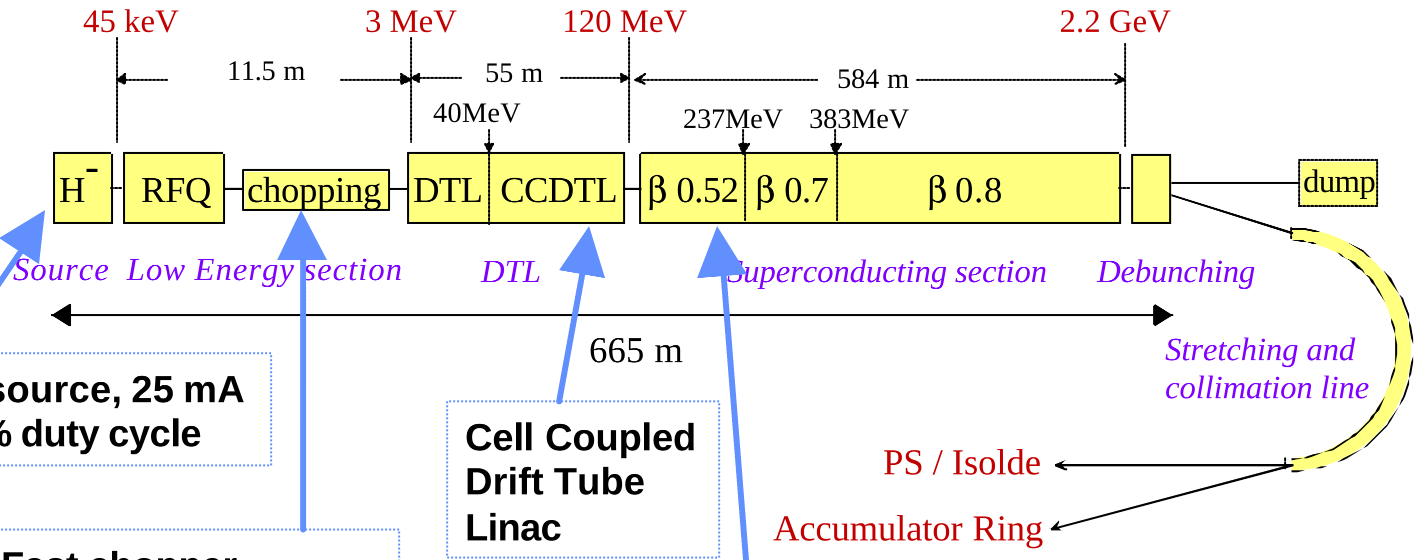
- In line with modern High Power Proton Accelerator projects (SNS, JKJ,…)
- Re-use of the LEP RF equipment (SC cavities, cryostats, klystrons, waveguides, circulators, etc.)



The LEP klystron

Storage of the LEP cavities in the ISR tunnel

The Superconducting Proton Linac: Design (1)



H- source, 25 mA
14% duty cycle

Cell Coupled Drift Tube Linac

Fast chopper
(2 ns transition time)

new SC cavities: b=0.52,0.7,0.8
5-cell b 0.8 cavities replacing 4-cell b 1 cavities in the LEP cryostat

2.2 GeV energy:
- **direct injection into PS**
- **threshold for p production**

RF system:
- **freq.: 352 MHz**
- **amplifiers: tetrodes and LEP klystrons**

The SPL: Design (2)

Section	Input energy (MeV)	Output energy (MeV)	No. of cavities	Peak RF power (MW)	No. of klystrons	No. of tetrodes	No. of Quads	Length (m)
Source, LEBT	-	0.045	-	-	-	-	-	2
RFQ	0.045	3	1	0.5	1	-	-	2.4
Chopper line	3	3	7	0.6	-	5	12	9.1
DTL	7	120	79	13.6	17	-	160	55
β=0.52	120	236	42	1.5	-	42	28	101
β=0.7	236	383	32	1.9	-	32	16	80
β=0.8 I	383	1111	52	9.5	13	-	26	166
β=0.8 II	1111	2235	76	14.6	19	-	19	237
Debunching	2235	2235	4	-	1	-	2	13
Total			293	42.2	51	79	263	665.5

54 cryostats,
32 directly from LEP,
the others reconstructed

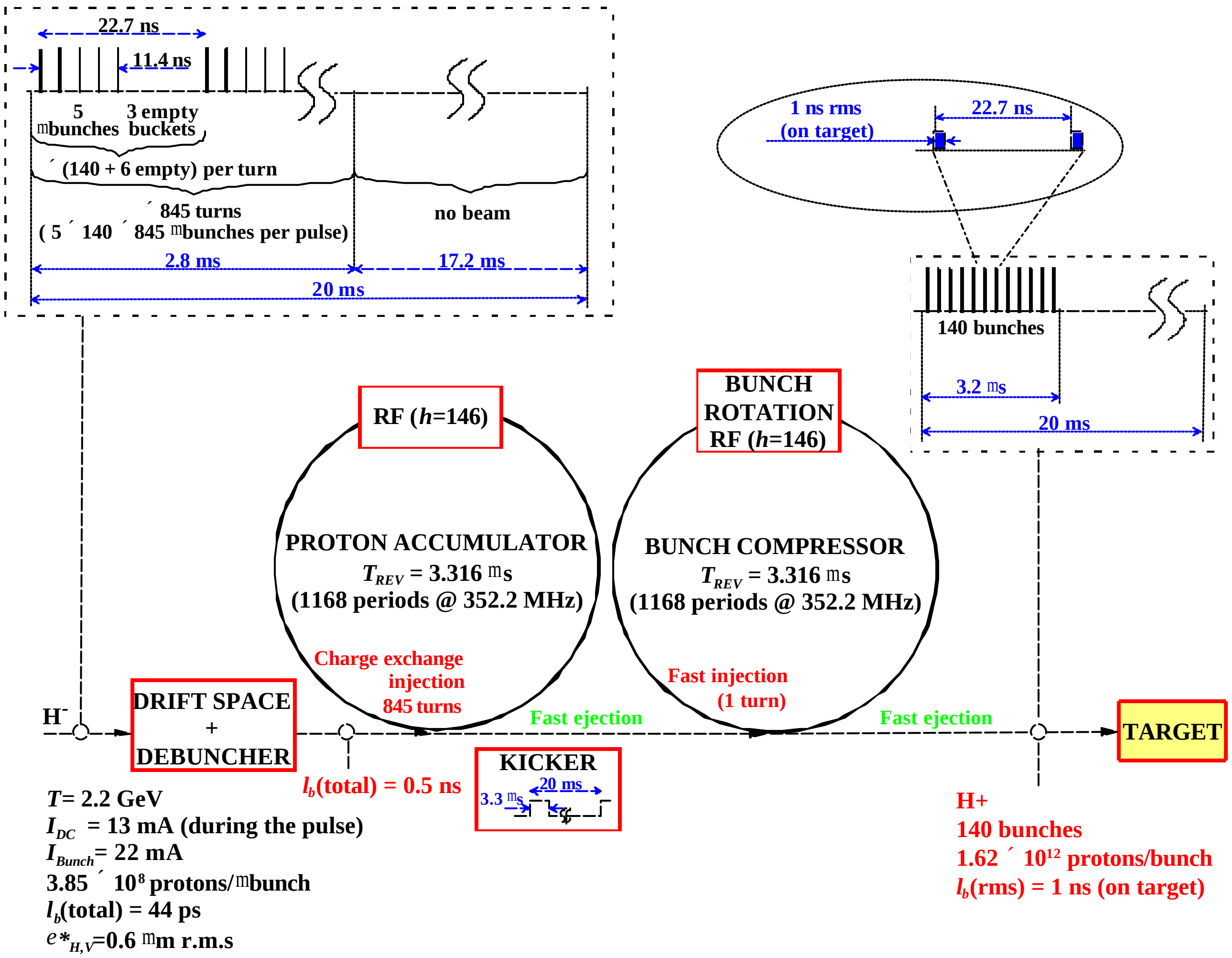
51 LEP-type klystrons (44 used in LEP)

SPL Beam Specifications

	Parameter	Value	Unit
MEAN PARAMETERS	Ion species	H-	
	Kinetic energy	2.2	GeV
	Mean current during the pulse	13	mA
	Duty cycle [mean beam power]	14 [4]	% [MW]
	Pulse frequency	50	Hz
	Pulse duration [number of H- per pulse]	2.8 [2.27 E 14]	ms [H^-/pulse]
FINE TIME STRUCTURE	Bunch frequency [minimum distance between bunches]	352.2 [2.84]	MHz [ns]
	Duty cycle during the beam pulse [number of successive bunches/number of buckets]	61.6 [5/8]	%
	Number of bunches in the accumulator [total number of buckets – empty buckets]	140 [146-6]	
	Maximum bunch current [maximum number of charges per bunch]	22 [3.85 E 8]	mA [H^-/bunch]
BUNCH CHARACTERISTICS	Bunch length (total)	0.13	ns
	Energy spread (total) [relative momentum spread (total)]	1.2 [~ 0.42 E-3]	MeV
	Normalised horizontal emittance (1 s)	0.6	mm
	Normalised vertical emittance (1 s)	0.6	mm
	Energy jitter during the beam pulse	< +- 0.5	MeV
	Energy jitter between beam pulses	< +- 2	MeV

Revised parameters are in red

The Accumulator – Compressor Scheme



Two Rings in the ISR Tunnel

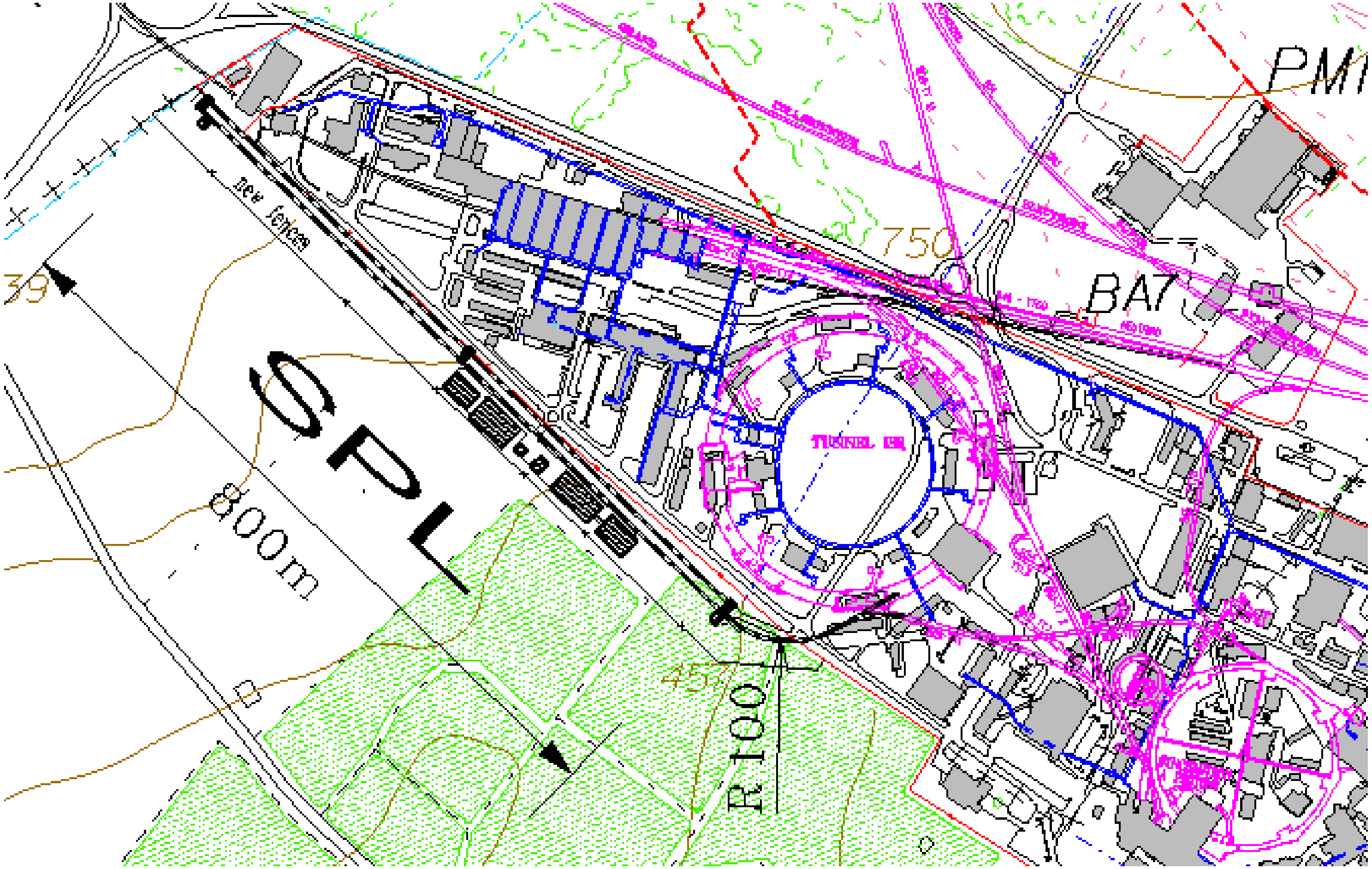
Accumulator:
3.2 μs burst of 140 bunches at 44 MHz

Compressor:
rms bunch length reduced to 1 ns

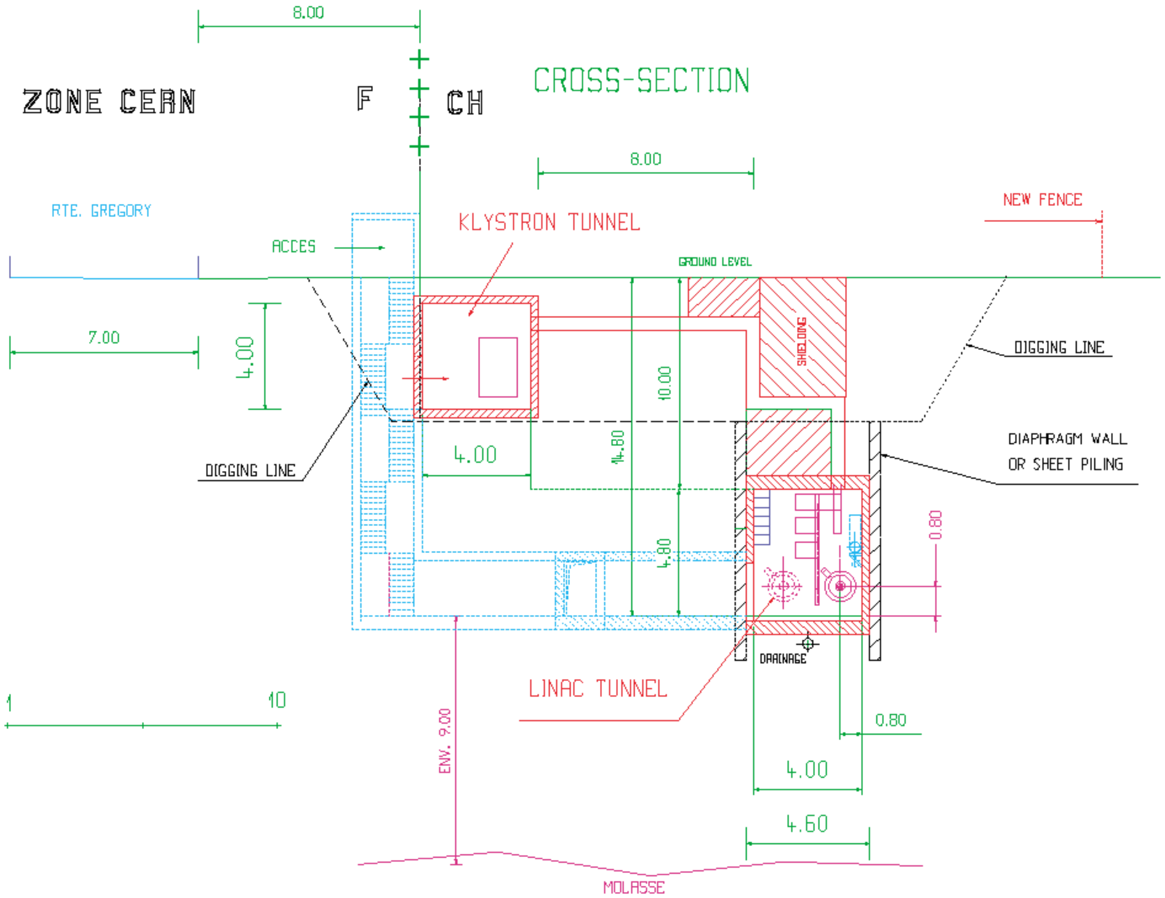
Characteristics of the beam sent to the target

Parameter	Value	Unit
Mean beam power	4	MW
Kinetic energy	2.2	GeV
Repetiton rate	**50**	Hz
Pulse duration	3.3	μs
Number of bunches	140	
Pulse intensity	**2.27** $\times 10^{14}$	p/pulse
Bunch spacing (Bunch frequency)	22.7 (44)	ns (MHz)
Bunch length (σ)	1	ns
Relative momentum spread (σ)	5×10^{-3}	
Norm. horizontal emittance (σ)	50	μm.rad

Layout on the CERN site



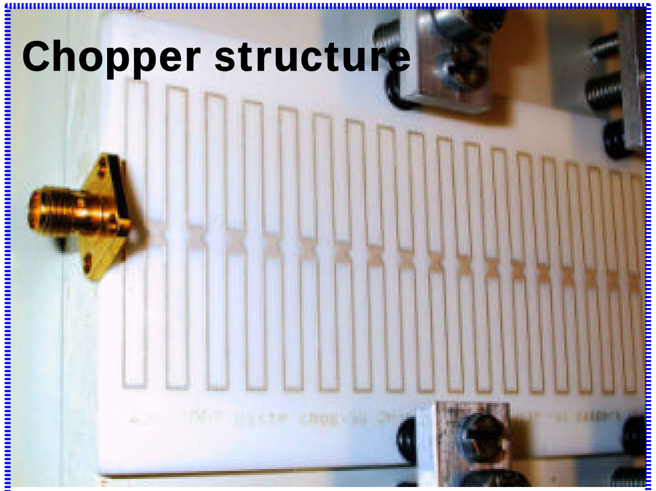
Cross section



SPL R&D Topics

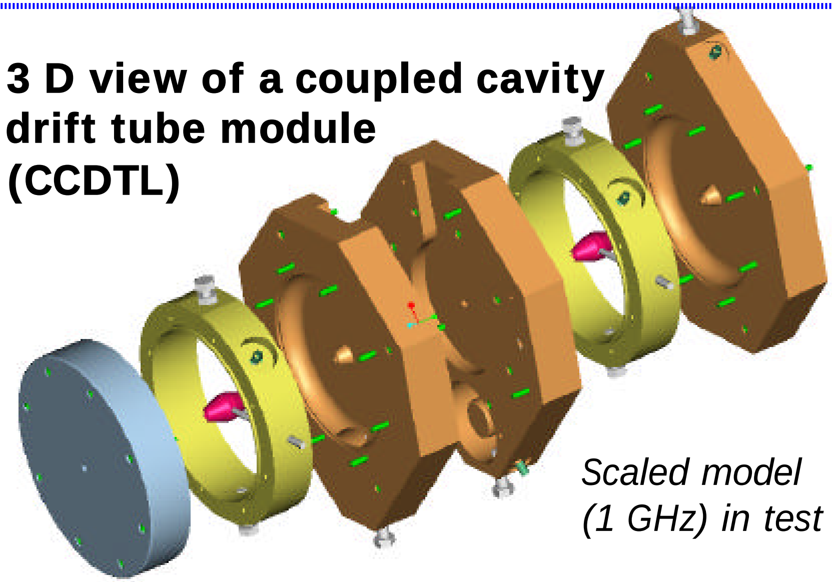
- Minimise beam loss to avoid activation of the machine (loss<1 W/m)
  - ***Beam Dynamics studies, optimise layout and beam optics***
- Chopper structure to create a time distribution in the beam that minimises losses in the accumulator
  - ***Travelling wave deflector with rise time <2 ns***
- Efficient room-temperature section (W<120 MeV)
  - ***CCDTL concept***
- Development of SC cavities for $\beta<1$
  - ***Sputtering techniques***
- Pulsing of LEP klystrons
  - ***Built for CW, operated at 50 Hz, 14% duty***
- Pulsing of SC cavities and effects of vibrations on beam quality
  - ***Low power (feedback), high power (phase and amplitude modulators) and active (piezos) compensation techniques***

SPL R&D – Low Energy

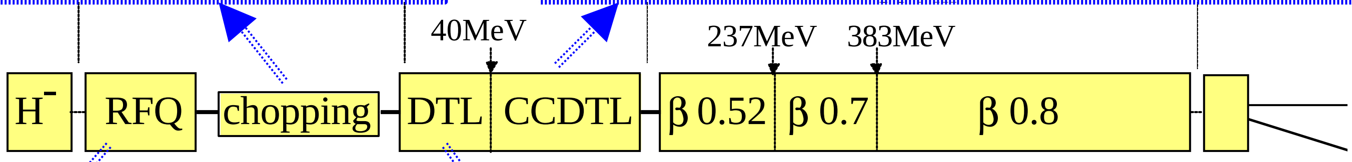


-Full performance prototype tested
-Driver amplifier in development

3 D view of a coupled cavity drift tube module (CCDTL)



Scaled model (1 GHz) in test



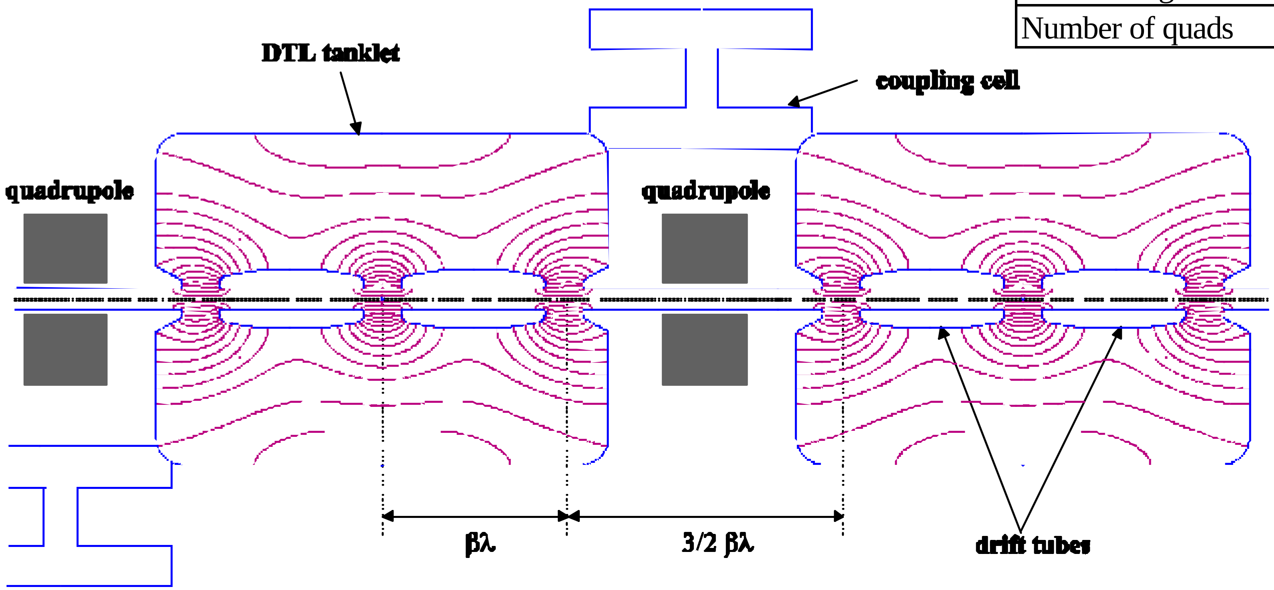
Collaboration on RFQs with CEA-IN2P3 (IPHI) and INFN Legnaro

352 MHz test place prepared (planned tests of CEA-built DTL structures in 2002)

SPL R&D – CCDTL structures

CCDTL characteristics

Input Energy	40	MeV
Output Energy	120	MeV
Number of tanks	76	
Gradient	3	MV/m
Lattice	FD	
Max. surface field	1.3	Kilp.
Aperture radius	14	mm
Synchronous phase	-25	deg
Length	47	m
Real estate gradient	1.7	MeV/m
Number of quads	38	



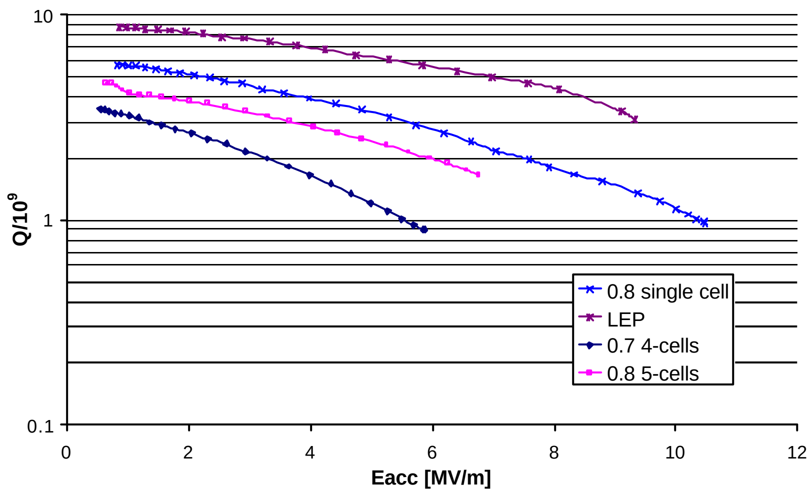
SPL R&D – Low Beta SC Cavities

The β=0.7 4-cell prototype

☆ CERN technique of Nb/Cu sputtering for β=0.7, β=0.8 cavities (352 MHz):

⇨ excellent thermal and mechanical stability (**very** important for pulsed systems)

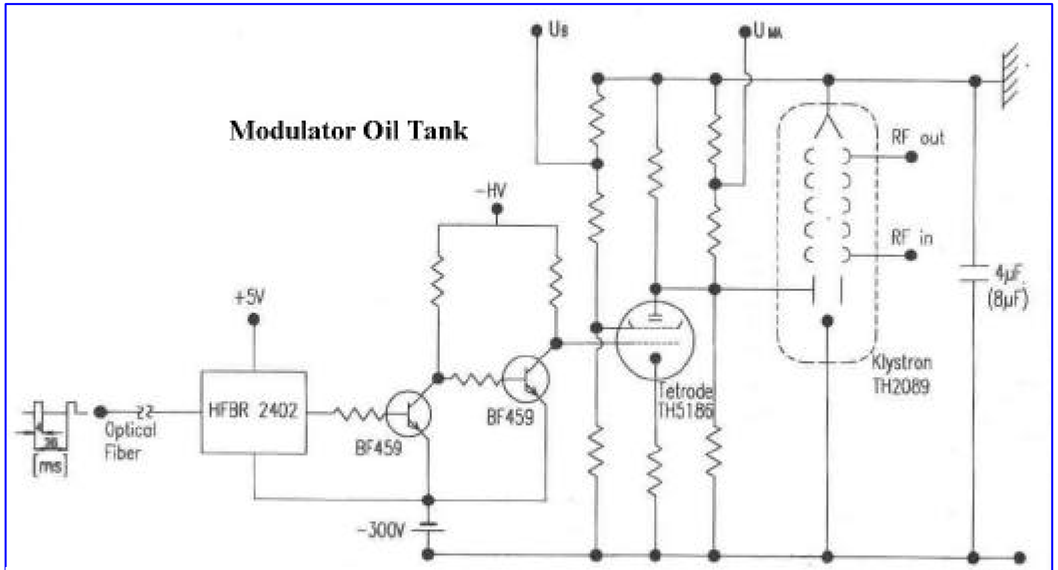
⇨ lower material cost, large apertures, released tolerances, 4.5 °K operation with $Q = 10^9$



☆ Bulk Nb or mixed technique for β=0.52 (one 100 kW tetrode per cavity)

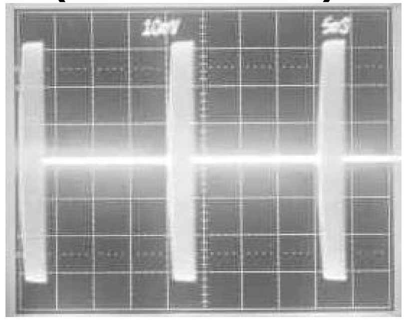
SPL R&D – Pulsing of LEP Klystrons

Mod anode driver

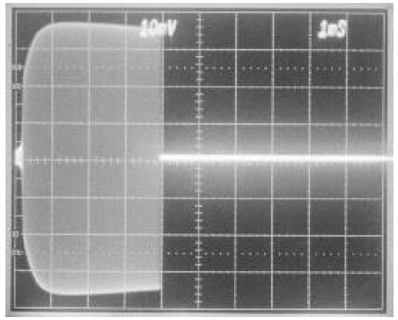


14/05/2001 - H. Frischholz

RF output power
(800 kW max.)



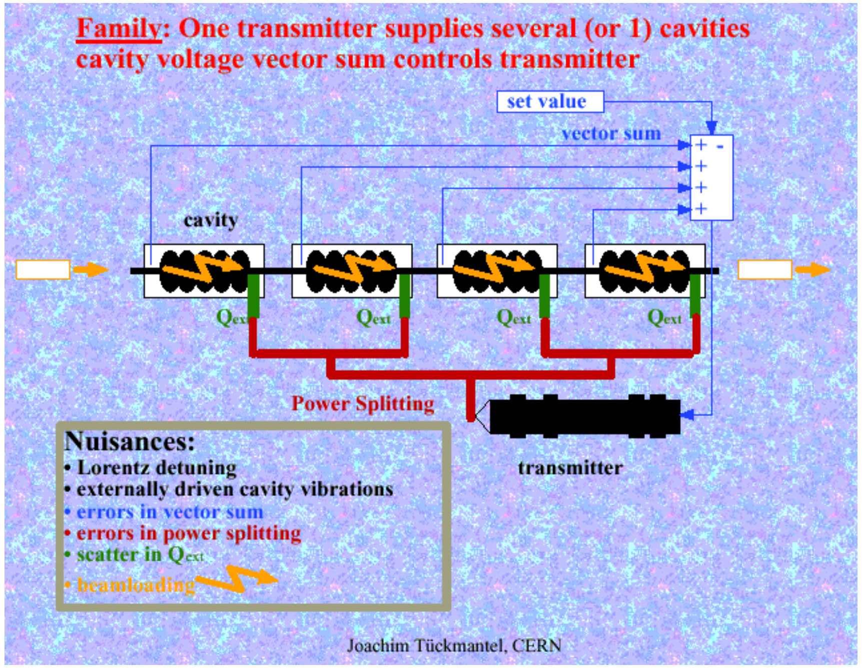
5 ms/div



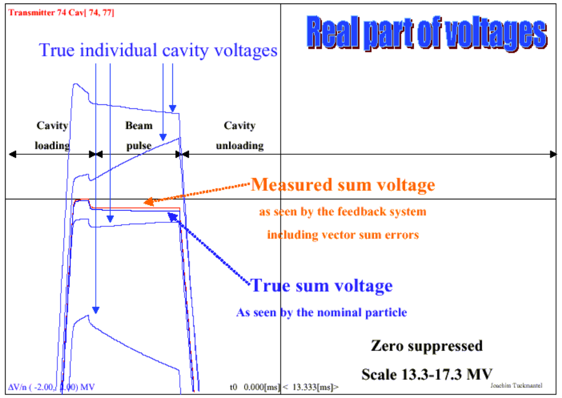
1 ms/div

Þ **LEP power supplies and klystrons are capable to operate in pulsed mode after minor modifications**

SPL R&D – RF power distribution & field regulation in the SC cavities

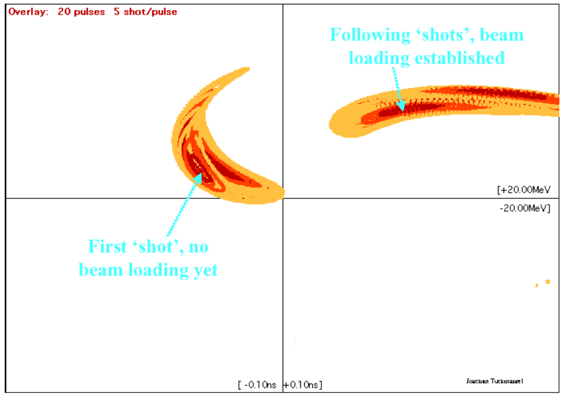


Effect on field regulation



Effect on the beam

Overlay plot of many phase space images



Þ unsolved problem ! Needs further investigation (high power phase & ampl. modulators, piezos,…)

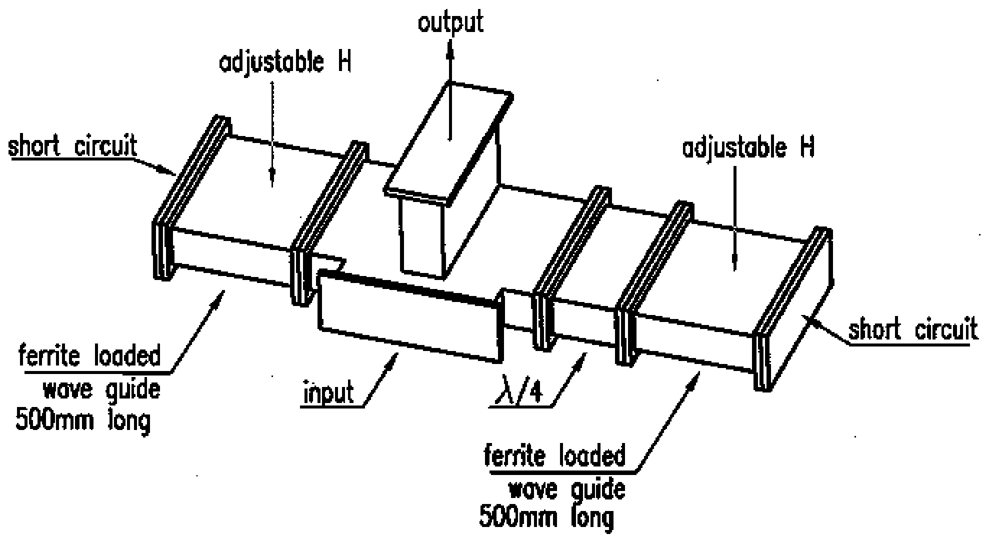
SPL R&D – High power phase/amplitude modulator

Specifications:

Frequency: 352 MHz
Peak output power: 650 kW
Output power range: +- 10 %
Output phase range: +- 22 deg.
Control speed: full range in 1 ms
Cost (series): < 20 kEuros

⇓

Can compensate for +- 20 Hz detuning of an SC cavity



High Power Phase & Amplitude Modulator

SPL R&D – Workplan in 2002

					EPAC 2002	NuFact 2002	LINAC 2002				
January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
			Mini-workshop on 3 MeV test place (CEA, IN2P3,LNL)						SPL study review		
				Selection of RFQ output energy and chopper line design						*Publication of the refined plans for the SPL study*	
								Request for EURISOL support from E.U.			
Beam dynamics study and SPL design optimisation											
H- source development											
			LLRF study and prototyping								
		Test prototype chopper driver									
			DTL tests with IPN (Grenoble) in PS South Hall								
								CCDTL tests in PS South Hall			
			Development of high power phase & amplitude modulator (AFT)								
Layout of the 120 MeV linac											
		Study of 120 MeV H- injection & accumulation in the PSB									
							Report on 120 MeV injector's proposal				

Staging

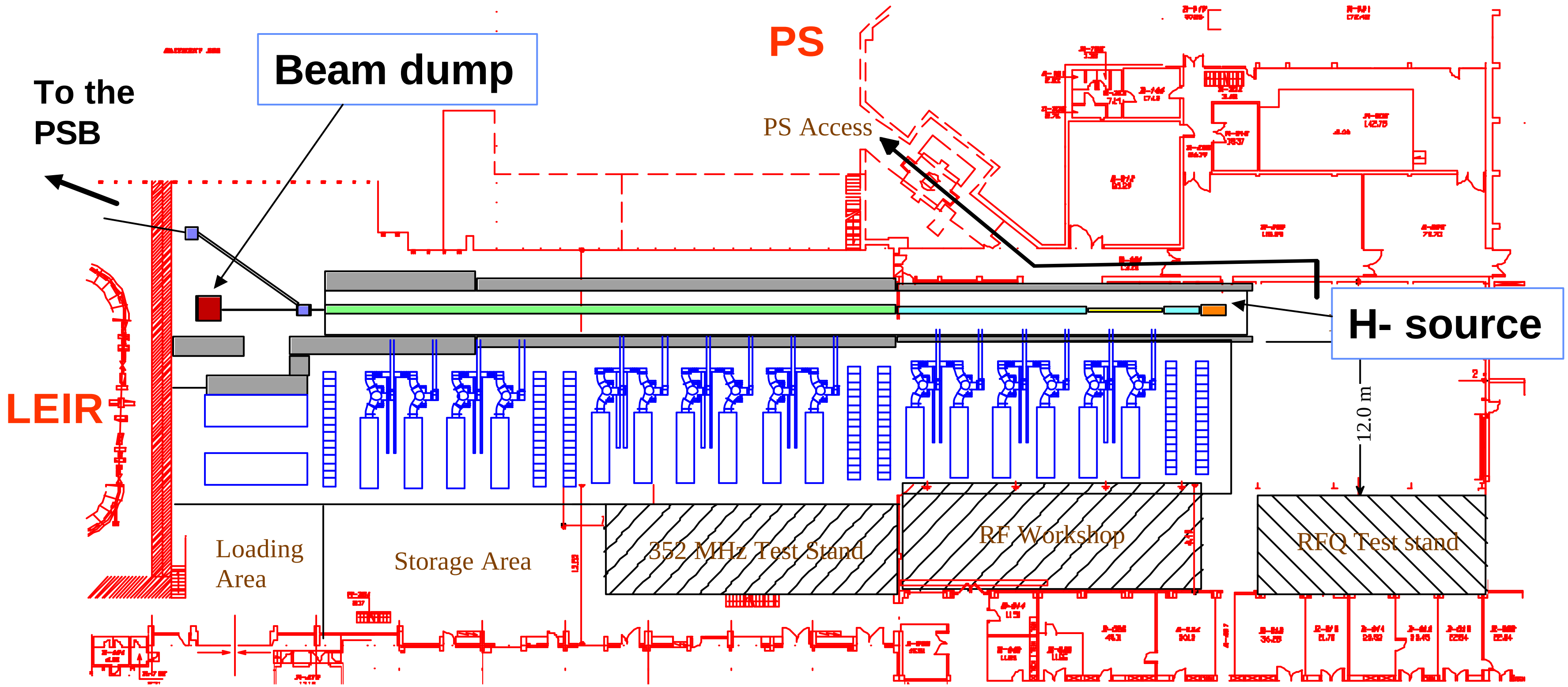
- **Test of a 3 (?) MeV H^- injector**
  - **In collaboration with CEA-IN2P3 exploiting the IPHI set-up**
- **120 MeV H^- linac in the PS South Hall [replacing LINAC 2 (50 MeV H+)]**
  - **Goal: increase beam intensity for CNGS and improve characteristics of all proton beams (LHC, ISOLDE…)**
  - **Under study: detailed design report with cost estimate in 2003**
  - **Needs new resources (collaborations, manpower, money)**
- **Full SPL**

120 MeV linac design

PARAMETERS	**Phase 1 (PSB)**	Phase 2 (SPL)		
Maximum repetition rate	**2**	50	Hz	
Source current *	**50**	30	mA	
RFQ current *	**40**	21	mA	
Chopper beam-on factor	**75**	62	%	
Current after chopper *	**30**	13	mA	
Pulse length (max.)	**0.5**	2.8	ms	
Average current	**15**	1820	μA	at 1 Hz, resp. 50 Hz
Max. beam duty cycle	**0.1**	14	%	
Max. number of particles per pulse	**0.9**	2.3	$\cdot 10^{14}$	
Transverse norm. emittance (rms)	**0.25**	0.25	π mm mrad	
Longitudinal emittance (rms)	**0.3**	0.3	π deg MeV	
Maximum design current	**30**		μA	at 2 Hz

Section	Input energy (MeV)	Output energy (MeV)	No. of cavities	Peak RF power (MW)	No. of klystrons	No. of tetrodes	No. of Quads	Length (m)
Source, LEBT	-	0.045	-	-	-	-	-	2
RFQ	0.045	3	1	0.5	1	-	-	3
Chopper line	3	3	*5*	*0.5*	-	*5*	12	*6*
DTL	3	120	13	11.9	15	-	149	64
TOTAL		120	19	12.9	16	5	161	75

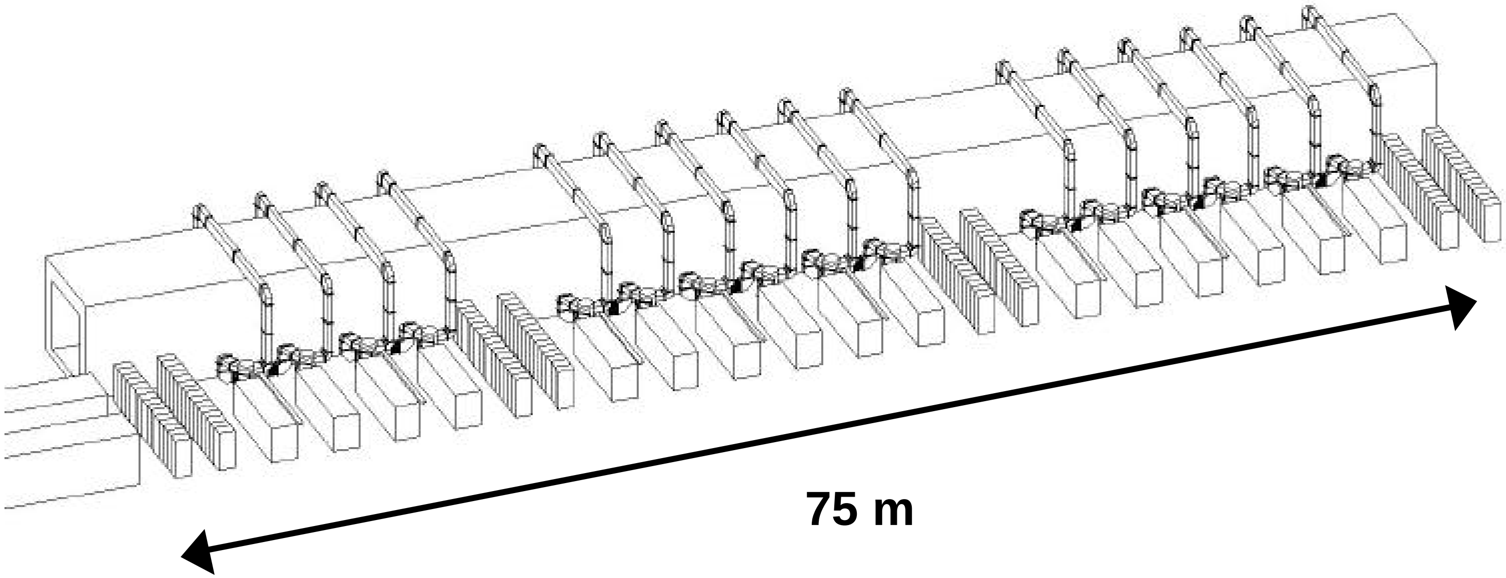
The SPL Front-end (120 MeV) in the PS South Hall (intermediate proton intensity increase)



Þ **Increased brightness for LHC, ´ 1.8 the flux to CNGS & ISOLDE, … (with upgrades to the PSB, PS & SPS)**

⇒very <u>cost-effective</u> facility: hall and infrastructure are available in the PS
all the RF is recuperated from LEP
shielding is done with LEP dipoles!

The 120 MeV Linac



(100 m available in PS South Hall)

Summary and Conclusion

- **The SPL study is supported, although with limited resources, and progress is made:**
  - **design is improving,**
  - **R&D is going on,**
  - **collaborations are active and more is encouraged !**

- **A staged approach is proposed to:**
  - **bring immediate benefits to the approved physics programme**
  - **help preserve and gradually strengthen a competent team**
  - **accelerate the realization of the complete SPL**

- **Continuation after 2002 depends upon CERN management decisions to solve the LHC crisis…**