CERN

The CERN Linac4
history, performance, perspectives

Maurizio Vretenar, CERN

TIARA Meeting19 June 2017

Linac4 Inauguration, 9th May 2017

Linac4 layout

Normal-conducting linear accelerator, made of:

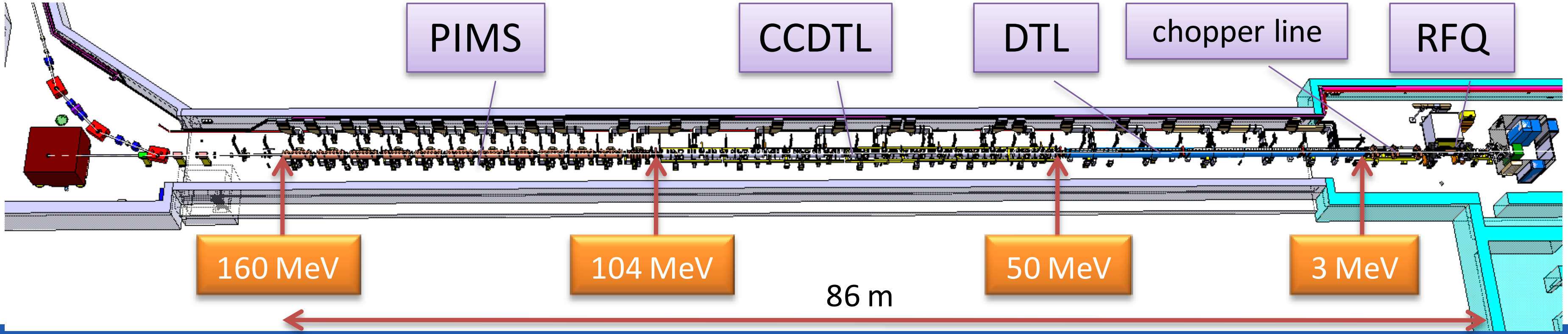
1. Pre-injector (source, magnetic LEBT, 3 MeV RFQ, chopper line)
2. Three types of accelerating structures, all at 352 MHz (standardization of components).
3. Beam dump at linac end, switching magnet towards transfer line to PSB.

☞ No superconductivity (not economically justified in this range of β and duty cycles);

☞ Single RF frequency 352 MHz (no sections at 704 MHz, standardised RF allows considerable cost savings) ;

☞ High efficiency, high reliability, flexible operation → 3 types of accelerating structures, combination of PMQ and EMQ focusing.

	Energy [MeV]	Length [m]	RF Power [MW]	Focusing
RFQ	0.045 - 3	3	0.6	RF
DTL	3 - 50	19	5	112 PMQs
CCDTL	50 - 102	25	7	14 PMQ, 7 EMQs
PIMS	102- 160	22	6	12 EMQs



Linac4: a team work

CEA SACLAY · РФЯЦ ВНИИЭФ · Budker Institute of Nuclear Physics · Narodowe Centrum Badań Jądrowych / National Centre for Nuclear Research ŚWIERK · JRC collaboration partner

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ony.Newborough,Christophe.Nicou,Pierre.Ninin,David.Nisbet,Remy.Noulibos,Miguel.Ojeda-Sandonis, Francesco.di.Lorenzo, Micheal.o.Neil, Chiara Bracco,
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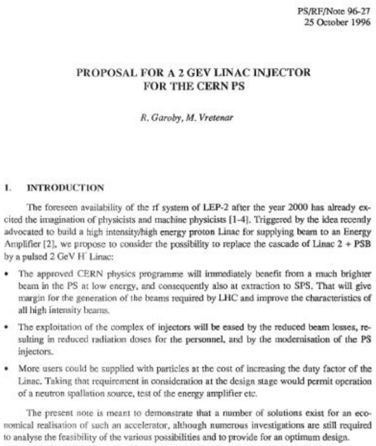
20 years of Linac4 – early work



PS/RF/Note 96-27
25 October 1996

PROPOSAL FOR A 2 GEV LINAC INJECTOR FOR THE CERN PS

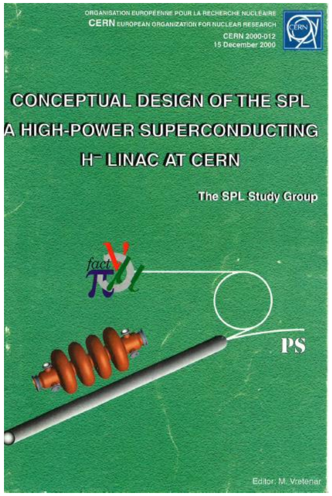
R. Garoby, M. Vretenar

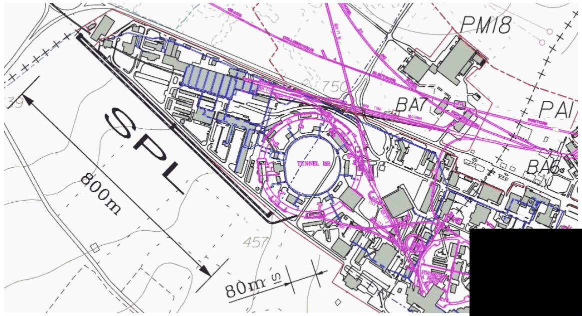
1. INTRODUCTION

The foreseen availability of the rf system of LEP-2 after the year 2000 has already excited the imagination of physicists and machine physicists [1-4]. Triggered by the idea recendy advocated to build a high intensity/high energy proton Linac for supplying beam to an Energy Amplifier [2], we propose to consider the possibility to replace the cascade of Linac 2 + PSB by a pulsed 2 GeV H^- Linac:

- The approved CERN physics programme will immediately benefit from a much brighter beam in the PS at low energy, and consequently also at extraction to SPS. That will give margin for the generation of the beams required by LHC and improve the characteristics of all high intensity beams.
- The exploitation of the complex of injectors will be eased by the reduced beam losses, resulting in reduced radiation doses for the personnel, and by the modernisation of the PS injectors.
- More users could be supplied with particles at the cost of increasing the duty factor of the Linac. Taking that requirement in consideration at the design stage would permit operation of a neutron spallation source, test of the energy amplifier etc.

The present note is meant to demonstrate that a number of solutions exist for an economical realisation of such an accelerator, although numerous investigations are still required to analyse the feasibility of the various possibilities and to provide for an optimum design.





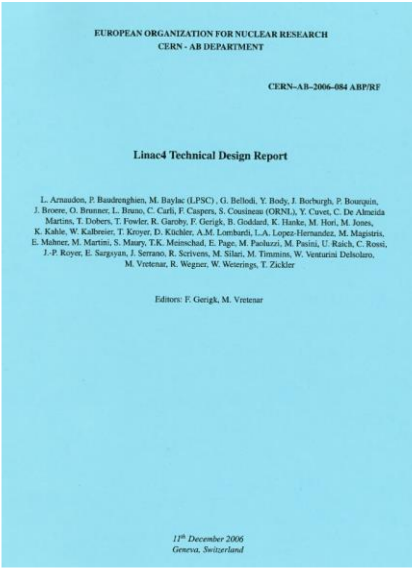
October 1996: first proposal (Garoby, Vretenar) of a new 2 GeV linac injector for the PS using decommissioned LEP hardware (what became the SPL, Superconducting Proton Linac)

2001: idea to build in a first stage only the room temperature part (120 MeV) of the SPL to inject into the PSB. Called «Linac4» and energy to 160 MeV from 2003.

2004: start R&D and prototyping for the new linac (small CERN budget and support from CARE, the first EU Integrating Activity for accelerators (2004-08).

1996 2001 2005

20 years of Linac4 - approval


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - AB DEPARTMENT

CERN–AB–2006–084 ABP/RF

Linac4 Technical Design Report

L. Arnaudon, P. Baudrenghien, M. Baylac (LPSC), G. Bellodi, Y. Body, J. Borburgh, P. Bourquin, J. Broere, O. Brunner, L. Bruno, C. Carli, F. Caspers, S. Cousineau (ORNL), Y. Cuvet, C. De Almeida Martins, T. Dobers, T. Fowler, R. Garoby, F. Gerigk, B. Goddard, K. Hanke, M. Hori, M. Jones, K. Kahle, W. Kalbreier, T. Kroyer, D. Küchler, A.M. Lombardi, L.A. Lopez-Hernandez, M. Magistris, E. Mahner, M. Martini, S. Maury, T.K. Meinschad, E. Page, M. Paoluzzi, M. Pasini, U. Raich, C. Rossi, J.-P. Royer, E. Sargsyan, J. Serrano, R. Scrivens, M. Silari, M. Timmins, W. Venturini Delsolaro, M. Vretenar, R. Wegner, W. Weterings, T. Zickler

Editors: F. Gerigk, M. Vretenar

11th December 2006
Geneva, Switzerland

December 2006: published the Linac4 Technical Design Report

21 June 2007: at its 142nd session, the CERN Council approves a White Paper presented by the DG R. Aymar including construction of Linac4 and study of the SPL

1 January 2008: the project officially starts (first project budget)

16 October 2008: Groundbreaking ceremony at the location of «Mount Citron»

2006 — 2007 — 2008 — 2009

20 years of Linac4 - infrastructure

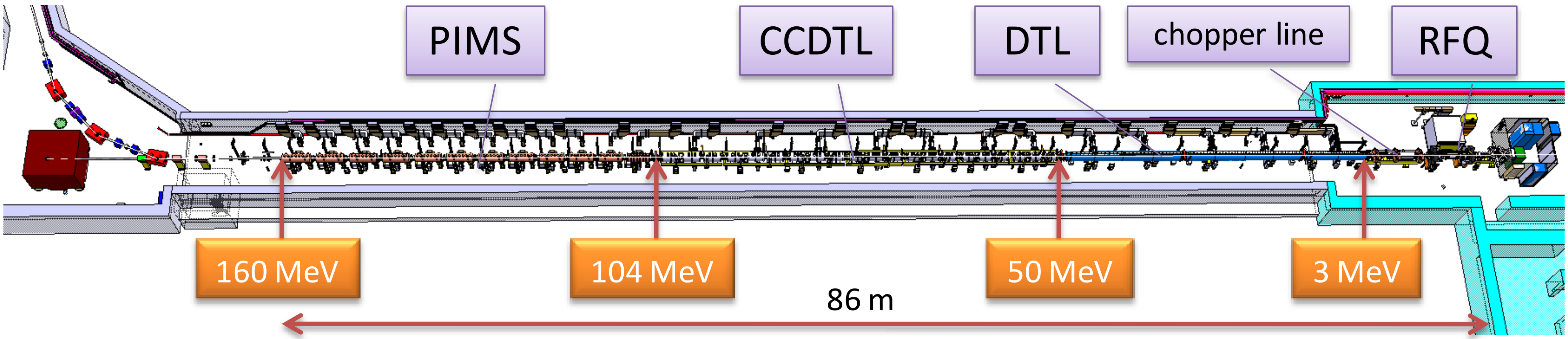
December 2010: delivery of the civil engineering works (on budget and schedule)

December 2012: infrastructure (electricity, cooling, ventilation, racks, cabling) complete, start installation of machine equipment and components.

2013: preparing for beam

2010 2011 2012 2013

20 years of Linac4 - commissioning



- RFQ in final location (3 MeV): 6 December 2013
- Drift Tube Linac tank 1 (12 MeV): 6 August 2014
- Drift Tube Linac tanks 2 & 3 (50 MeV): 24 November 2015
- CCDTL (104 MeV): June 2016
- PIMS (160 MeV final energy): 25 October 2016

2014 2015 2016 2017

(exactly) 20 years from first idea to first beam

PS/RF/Note 96-27
25 October 1996

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FOR THE CERN PS

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Linac 4 reached its energy goal

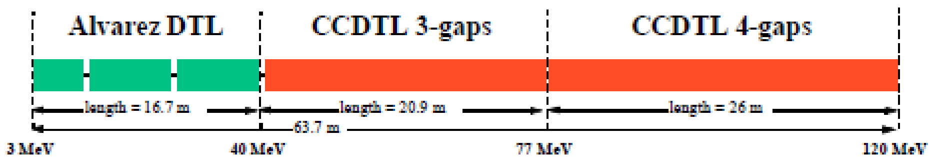
by Stefania Pandolfi

On 25 October 2016, Linac 4 reached its design energy of 160 MeV through putting successfully into operation the 12 Pi-Mode Structures (PIMS) (Image: Andrew Hara)

CERN's new linear accelerator (Linac 4) has now accelerated a beam up to its design energy, 160 MeV. This important milestone of the accelerator's commissioning phase took place on 25 October.

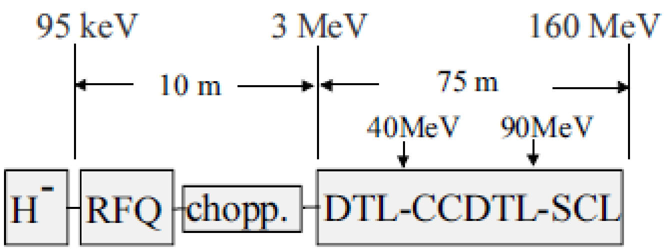
Linac 4 is scheduled to become the source of proton beams for the CERN accelerator complex, including the Large Hadron Collider (LHC) after the long shutdown in 2019-2020. It will replace the existing Linac 2 as the first link in the accelerator chain, which is currently accelerating protons to 50 MeV.

Evolution of Linac4 design



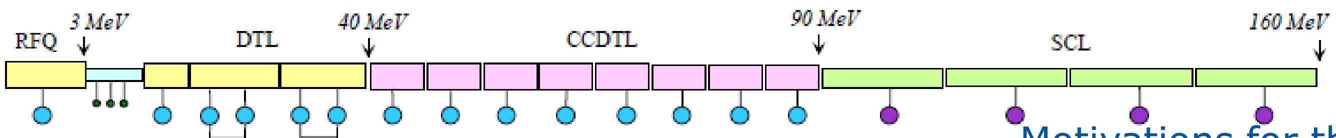
1: 2002, 30 mA, 120 MeV, 352 MHz

Although the basic principles remained the same (basic frequency 352 MHz, only NC, current 30/40 mA) design and parameters have changed several times.



2: 2004, 30 mA, 160 MeV, 352/704 MHz

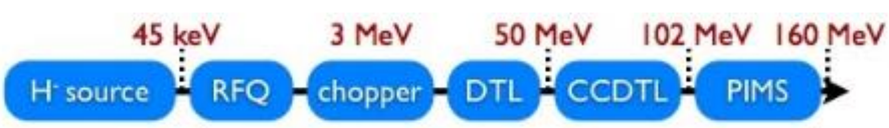
The most important milestone is the transition between R&D and construction: the impact on Linac4 was the replacement of a Side Coupled Linac (SCL) at 704 MHz by a Pi-Mode Structure (PIMS) at 352 MHz, when SCL design and protypying were well advanced.



3: 2006, 40 mA, 160 MeV, 352/704 MHz

Motivations for the change SCL/PIMS:

- Standardisation of the RF system on a single frequency and one type of klystron (but some reduction in RF efficiency ZT^2).
- Less manpower required for tuning and construction (5 times less cells!)
- Easier to attract internal and external interest for a new type of structure



Hz

4: 2007, 40 mA, 160 MeV, 352 MHz

EC support in a critical phase

HIPPI: High Intensity Pulsed Proton Injectors (2004-2008)

Joint research Activity in CARE, the first IA for accelerator R&D

Main objective: *Research and development of the technology for high intensity pulsed proton linear accelerators up to an energy of 200 MeV.*

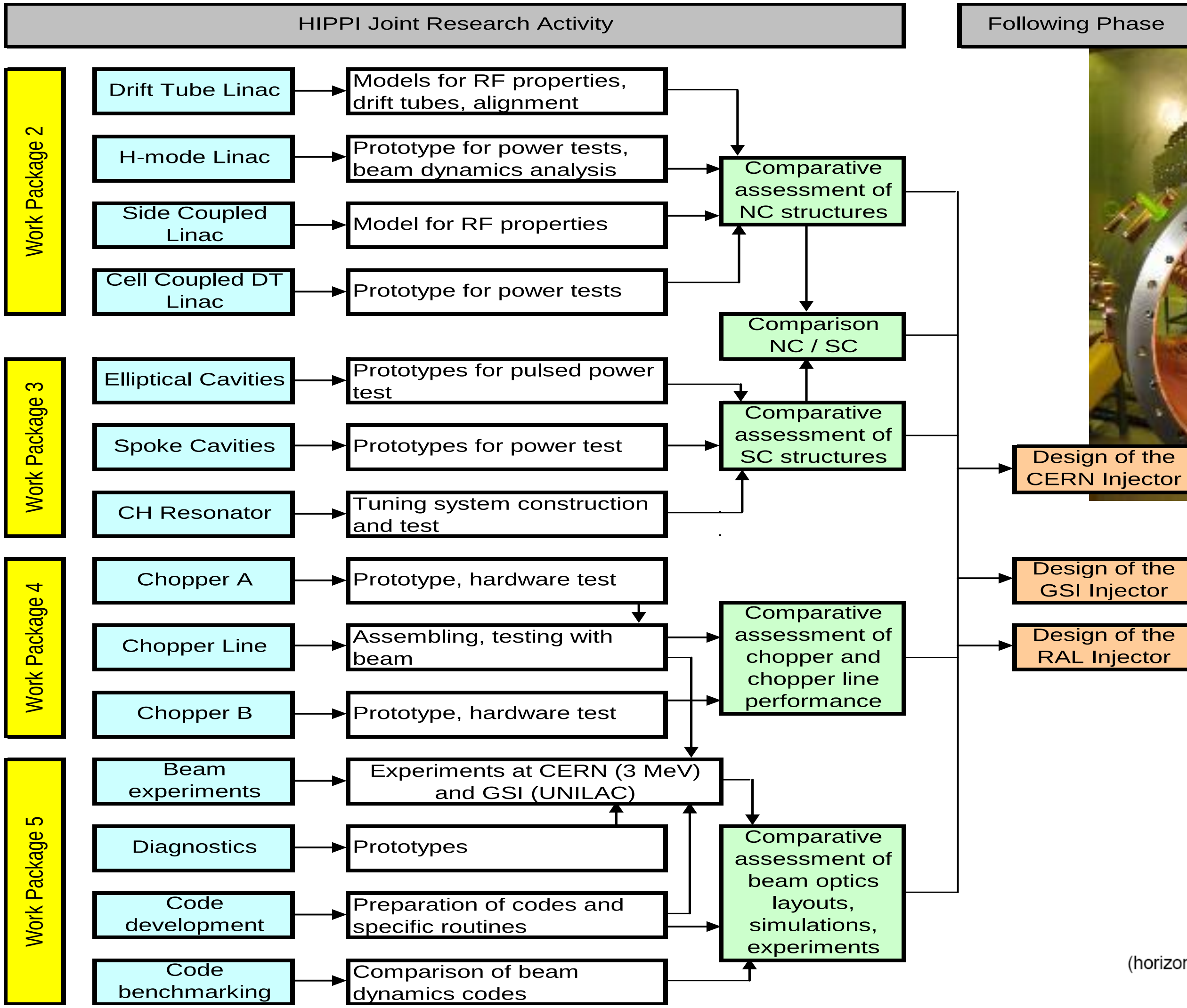
Applications of the HIPPI results: *Upgrade of the linac injectors for GSI, CERN and RAL.*

10 participating laboratories: *RAL, CEA, CERN, FZJ, GSI, IAP-FU, INFN-MI, INFN-NA, LPSC, IPNO*

Budget: *14.7 M€, EU contribution 3.6 M€ (~25%)*

Goal: advance jointly linac technologies in Europe, beyond SNS and JPARC
HIPPI has built in 5 years a total of 12 prototypes of accelerating structures and has developed and validated the linac beam optics codes.

HIPPI Workplan (from proposal, 2003)



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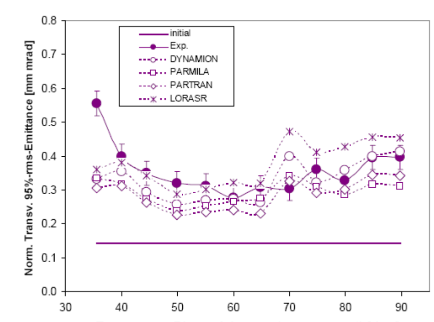


The contribution of CARE/HIPPI

Developing some of the technologies for Linac4 within a European project has provided:

1. An environment for collaboration and exchange of information with the different European actors (synergies and network of competences).
2. A clear vision of the advantages/disadvantages of different technical options that has allowed converging on an optimised design.
3. A welcome support for R&D (budget and recognition) in the critical time before project approval.

During the HIPPI lifetime, the Linac4 proposal was submitted and approved, and the proposal for the FAIR proton linac was submitted.

One additional comment: when Linac4 had a problem with the ion source (2010), the crash programme to develop and build a new ion source started from the high-duty H- ion source that had been developed within the sLHC-PP project.

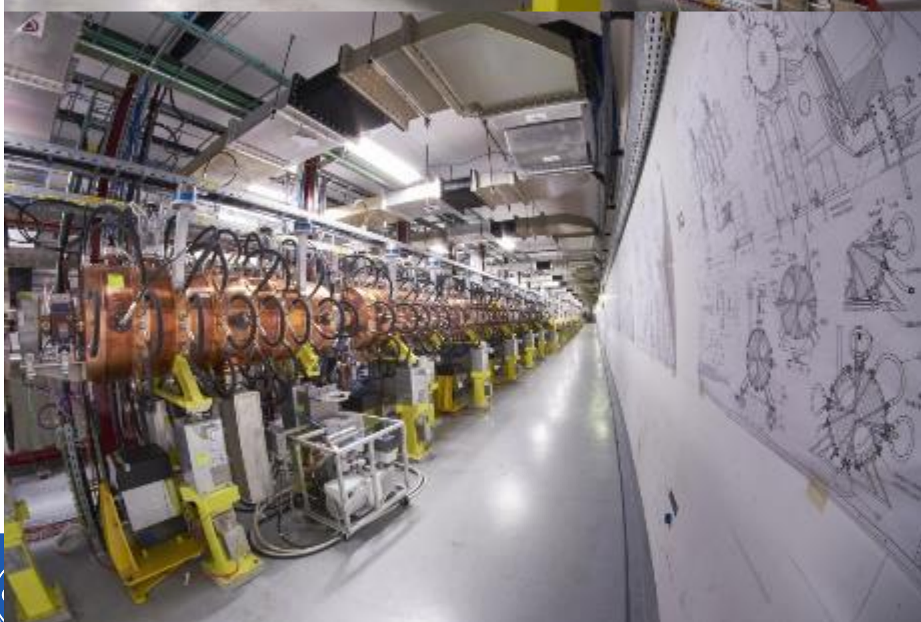
Linac4 main innovations

- 2 types of accelerating structures (CCDTL and PIMS) used for the first time in the world.
- New original Drift Tube Linac mechanical design (patented) and tuning scheme.
- Extensive use of permanent magnet quadrupoles (127/158)
- Innovative scheme for chopping of the beam at low energy
- New CERN-made H- ion source design.
- (*Touching wood…)* one of the most reliable RFQs in accelerator history.
- A special RF distribution scheme that allows re-using the LEP klystrons.
- An upgradable design in duty cycle and current (and a tunnel that can be extended to higher energies…)

A few lessons learned

- Problems always appear where you don't expect them: the ion source was considered so critical that we copied an existing (working) design, which did not work at CERN. We have chosen a proven type of vacuum joints, but the manufacturer changed the parameters and we have lost 6 months chasing the problem…
- Collaborations are of paramount importance to share the workload and to have access to a network of competences.
- It is essential to have available as soon as possible a test stand to get experience on real components and real beams.
- For a smooth commissioning, it is vital to have offhand a set of simulation codes with an accurate modeling of the machine (and a reliable diagnostics!).

Linac4 today

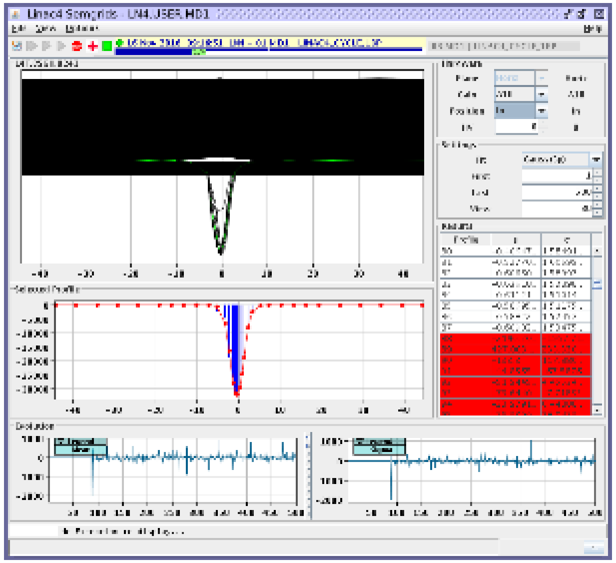


Beam measurements – 160 MeV

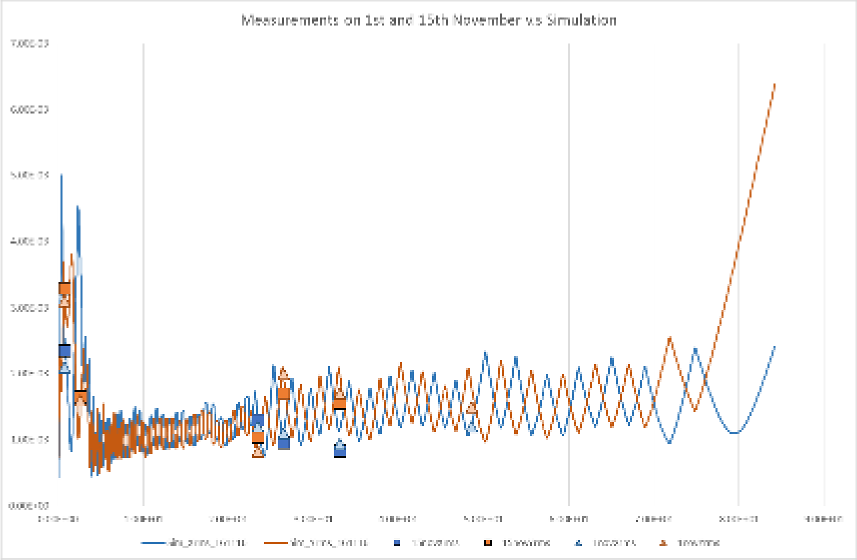
Commissioning with beam current 15 mA, emittance well within specifications

Excellent agreement between beam simulations and measurements

October 2016 - March 2017: beam optimisation at 160 MeV and test of the PS Booster injection equipment (temporary installation in Linac4 line).



Transverse beam profile at 160 MeV



Transverse beam size along Linac4 – simulations (lines) and measurements (points)

Ion source

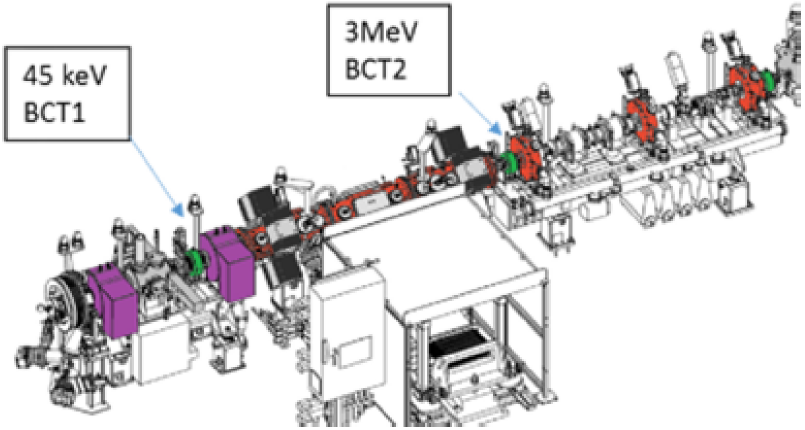
A word on the source

Many improvement since march 2015

1) Intensity
2) Stability
3) Auto-Pilot (automatic regulation of critical source parameters for increased stability)
4) Caesiation with autopilot , time needed went from half day w/o beam to few hours in degraded beam conditions

Parallel program at the test stand

1) Control of the emittance
2) Optimised electrode shape
3) Matching into the LEBT
4) Mastering neutralisation?



Current at 3 MeV before chopping	
Today's LINAC4	20 mA
Record LINAC4	30 mA
Nominal LHC Inj. Upgrade	40 mA
Ultimate LINAC4	60 mA
The gap to the nominal LIU can be compensated with twice the injected number of turns in the PSB.	

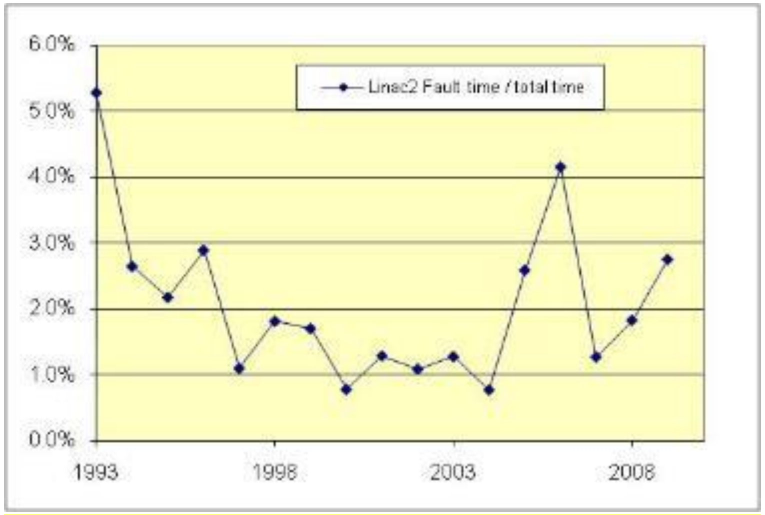
Next step: reliability run

Reliability is one of the main challenges of Linac4

Goal of Linac4 is availability > 95%. Will be necessarily lower in the initial phase

Reliability Run:
Debugging off-line for the initial problems

Objective for the Reliability Run:
reaching **90 – 95 %** availability at the end of the RR.



Example:
Linac2 fault rate after the installation of the new RFQ2 in 1993.

2017												**2018**											
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Shut down	Half Sector Test		Debuncher installation		Reliability Run						Shut down		Spare for Reliabilty Run		interventions, repairs					Beam recommissioning			Shut down
EYETS											shutdown												LS2

Connection to the PS Booster during LS2 (2019-20)

Thank you for your attention

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