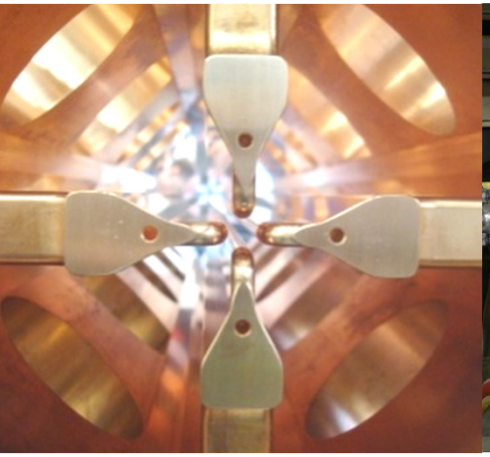
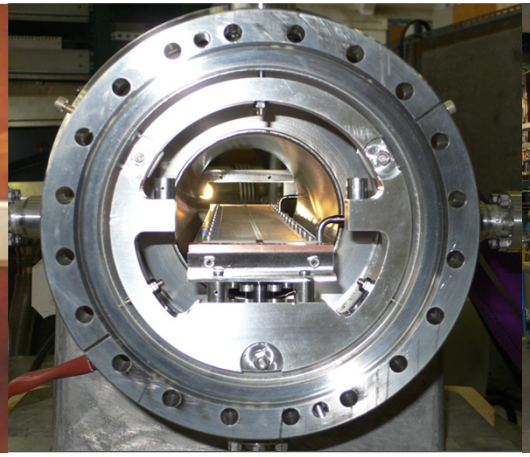
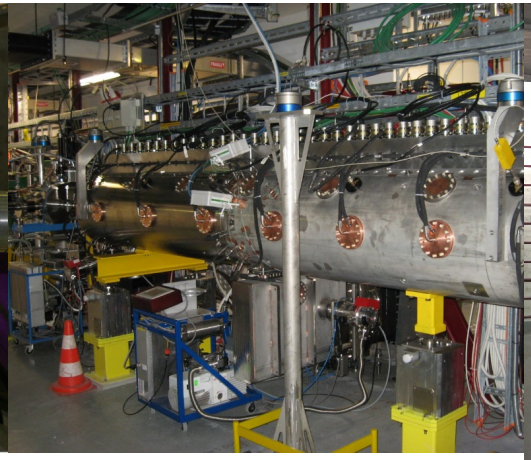
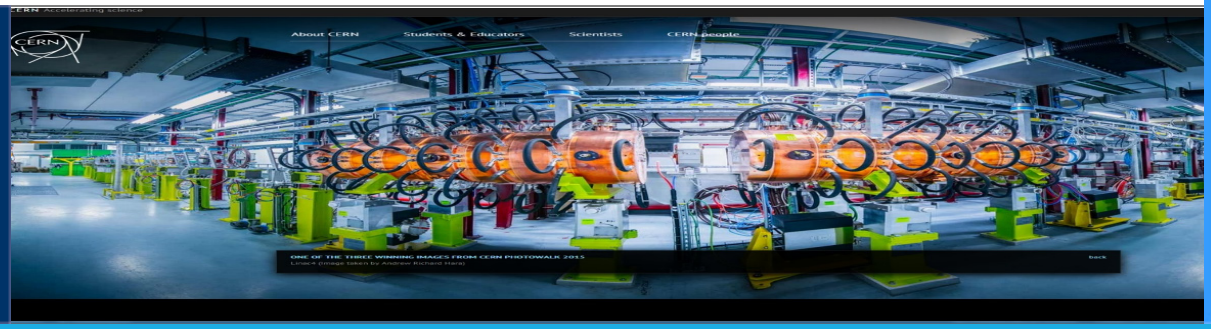





Linac4 Commissioning

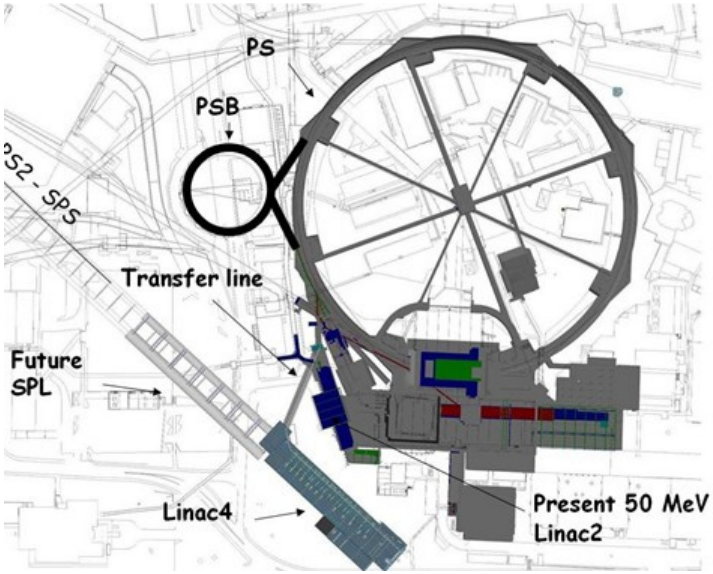
V. Bencini
on behalf of Alessandra M Lombardi and the LINAC4 Team



Oliver.Abevrle,Davide.Aguglia,Luca.Arnaudon,Philippe.Baudrenghien, Giulia.Bellodi, Caterina.Bertone, Yannic.Body, Jan.Borburgh, Enrico.Bravin, Olivier.Brunner,Jean-Paul.Burnet,Marco.Buzio,Christian.Carli,Etienne.Carlier,Miguel.Cerqueira.Bastos,julie.coupard,Jean-Marc.Cravero,Pierre.Dahlen,Benoit.Daudin,Jurgen.de.Jonghe,Nuno.Dos.Santos,L.Ducimetiere,Tony.Fowler,jean-frederic.fuchs,Delphine.Gerard,Frank.Gerigk,jean-michel.giguet,Silvia.Grau,Jean-Claude.Guillaume,Louis.Hammouti,Klaus.Hanke,Michael.Hourican,Mark.Jones,Quentin.King,Ioan.Kozsar,Jean-Baptiste.Lallement,Gilles.Le.Godec,Franco.Lenardon,Alessandra.Lombardi,Luz.Lopez-Hernandez,Serge.Mathot,Stefano.Moccia,Eric.Montesinos,Antony.Newborough,David.Nisbet,Mauro.Paoluzzi,Aurelie.Pascal,Daniel.Perrin,Jerome.Pierlot,Serge.Pittet,Bruno.Puccio,Uli.Raich,Suitbert.Ramberger,Carlo.Rossi,Richard.Scrivens,Lars.Soby,Jocelyn.Tan,Hugues.Thiesen,Pierre.Alexandre.Thonet,Giovanna.Vandoni,Maurizio.Vretenar,Wim.Weterings,Christos.Zamantzas,Thomas.Zickler, Elena.Benedetto,Alessandro.Bertarelli,Etienne.Carlier,Jean-Pierre.Corso,julie.coupard,Yves.Cuvet,Alessandro.Dallocchio,L.Ducimetiere,Gilles.Favre,Alan.Findlay,Jan.Hansen,Lars.Jensen,Rhodri.Jones,Detlef.Kuchler,Jean-Michel.Lacroix,Bettina.Mikulec,Dominique.Missiaen,john.molendijk,Benoit.Riffaud,Federico.Roncarolo,Carlo.Rossi,Jose-Luis.Sanchez.Alvarez,Andrzej.Siemko,Marco.Silari,Lars.Soby,Didier.Steyaert,Jocelyn.Tan,Pierre.Alexandre.Thonet,joachim.vollaire,Rolf.Wegner,Sylvain.Weisz, Michel.Arnaud,Luca.Arnaudon,Sonia.Bartolome,Cedric.Baud,cyrille.patrick.bedel,aurelio.berjillos,christian.marc.bernard,Ana-Paula.Bernardes,Alessandro.Bertarelli,Sebastien.Bertolo,thomas.william.birtwistle,Jan.Blaha,Sebastien.Blanchard,Yannic.Body,philippe.boisseaux-bourgeois,robert.borner,Olivier.Brunner,pawel.andrzej.burdelski,Didier.Chapuis,Ahmed.Cherif,Laurent.Colly,Fabio.Corsanego,Jean-Pierre.Corso,julie.coupard,Christophe.Coupat,Jean-Marc.Cravero,Olivier.Crettiez,Maryse.Da.Costa,Alessandro.Dallocchio,jose.delagama,gian.piero.di.giovanni,Tobias.Dobers,Gerald.Dumont,John.Etheridge,Gilles.Favre,ja.ferreira,Ramon.Folch,Katy.Foraz,Robert.Froeschl,jean-frederic.fuchs,Anne.Funken,javier.galindo,georgi.minchev.georgiev,Frank.Gerigk,jean-michel.giguet,Gael.Girardot,David.Glenat,Paulo.Gomes,Marine.Pace,Silvia.Grau,Jean-Louis.Grenard,Damien.Grenier,Serge.Grillot,jean-francois.gruber,Roberto.Guida,greta.guidoboni,Jean-Claude.Guillaume,abel.gutierrez,Louis.Hammouti,Jan.Hansen,Steve.Hutchins,Stephane.Joffe,Mark.Jones,Ioan.Kozsar,Jean-Michel.Lacroix, David.Landre,raphael.langlois,jean.marc.lassauce,patrick.lelong,Jacques.Lettry,Yann.Lupkins,Jose.Marques,Christophe.Martin,alex.martinez,Pablo.Martinez.Yanez, Albert.Masson,Christian.Mastrostefano,Simon.Mataguez,Serge.Mathot,Bettina.Mikulec,Stefano.Moccia,Richard.Mompo,Boris.Morand,richard.francis.morton,Antony.Newborough,Christophe.Nicou,Pierre.Ninin,David.Nisbet,Remy.Noulibos,Miguel.Ojeda-Sandonis, Francesco.di.Lorenzo, Micheal.o.Neil, Chiara Bracco, Federico Roncarolo, Daniel Noll, Georgios Voulgarakis, Vittorio Bencini

Outline

- LHC Injector Upgrade
  - Why LIU?
  - CERN complex upgrade
- Linac4 commissioning
  - Commissioning
  - Measurements
  - Current limitations
- Reliability and beam quality run
  - Reliability run and fault tracks
  - Timeline
  - Beam quality run
- Conclusions and next steps



LHC Injectors Upgrade

VB4
VB14

Why LHC Injectors Upgrade?

$$\mathcal{L} = \frac{\gamma}{4\pi} \times f_r \times \frac{F}{\beta^*} \times n_b \times \frac{N_b^2}{\varepsilon_n}$$

N_b	number of particles per bunch
n_b	number of bunches
f_r	revolution frequency
ε_n	normalised emittance
β^*	beta value at Ip
F	reduction factor due to crossing angle

From machine design, optics and limitations (e-cloud,etc)

Brightness from injectors: defined at low energy

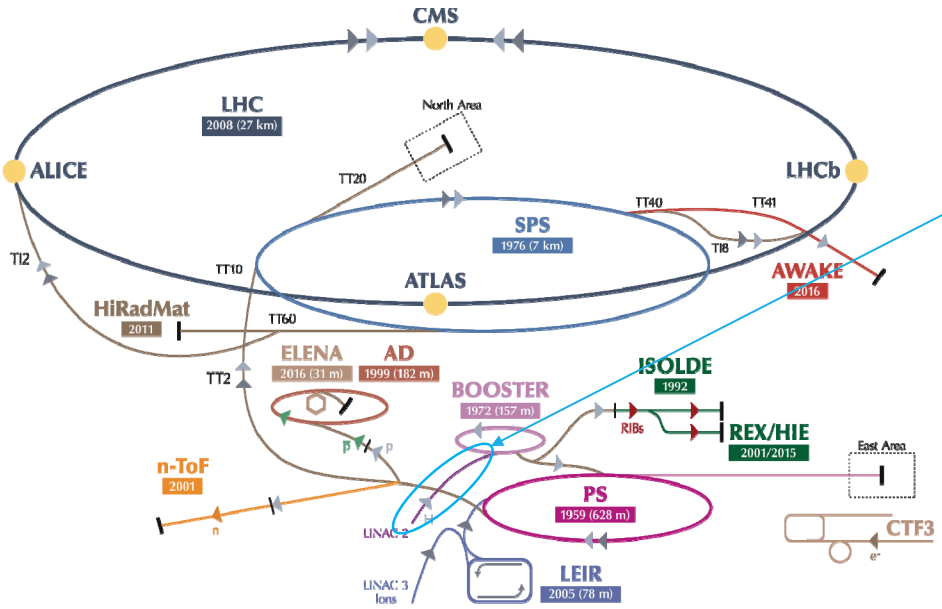
High Luminosity LHC

+

LHC Injectors Upgrade

= TEN TIMES MORE LUMINOSITY IN LHC!!

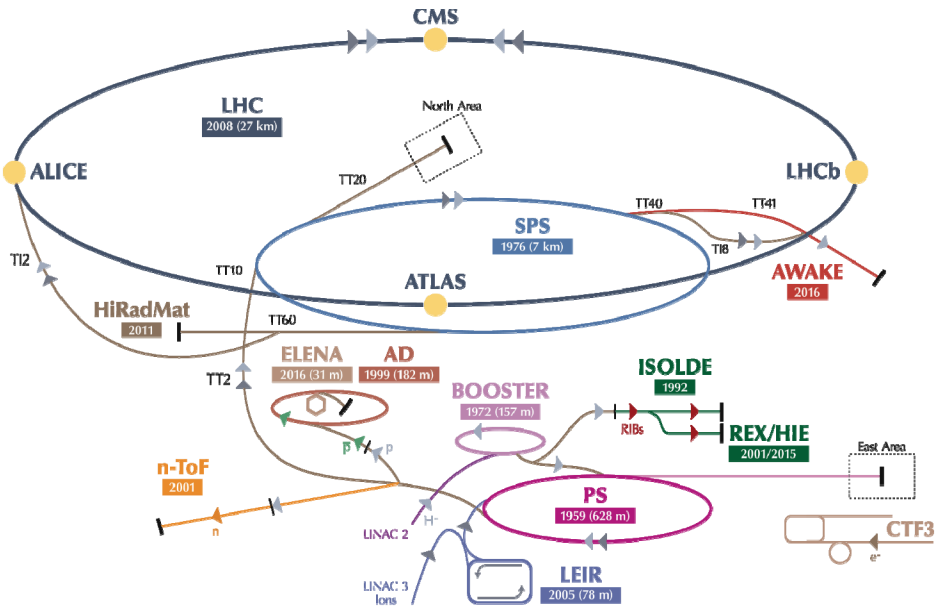
CERN accelerators complex

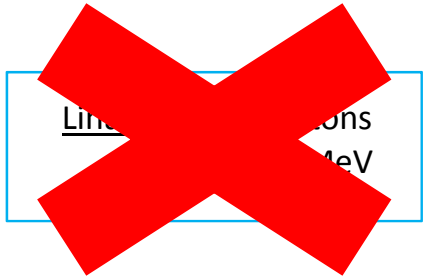


Linac2

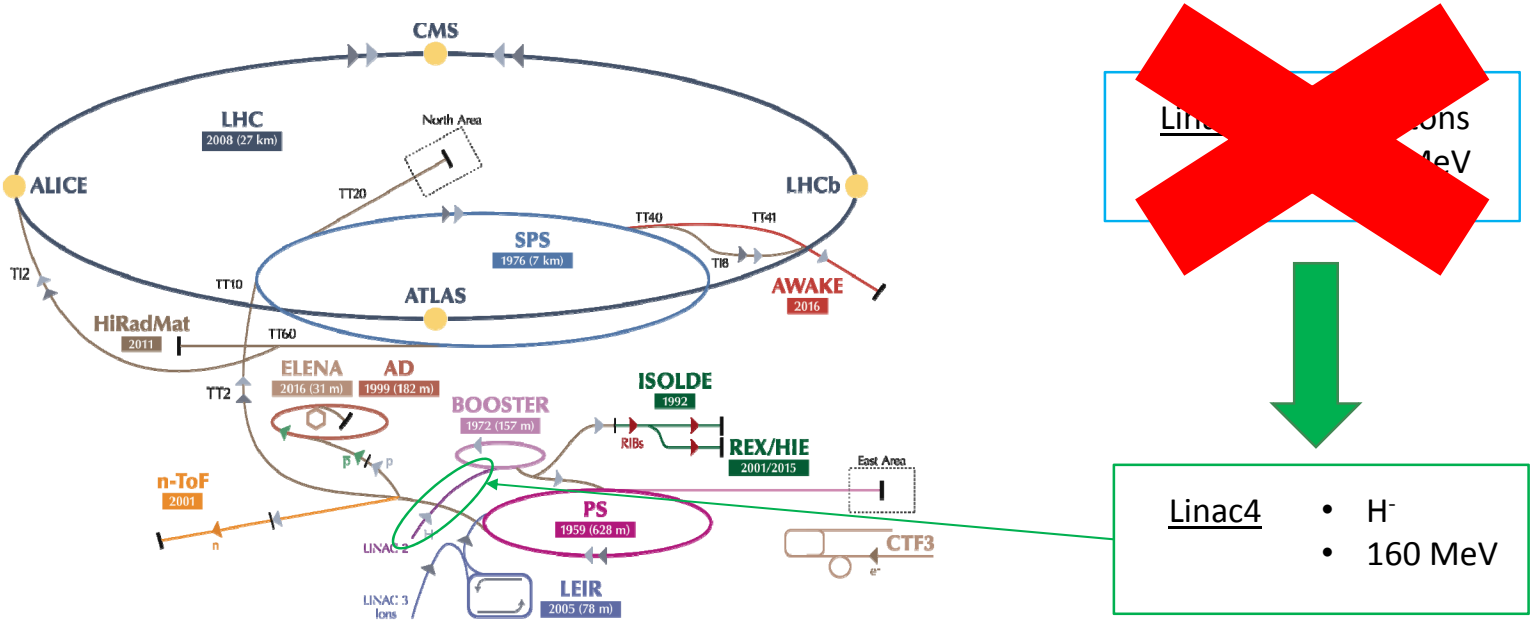
- Protons
- 50 MeV

CERN accelerators complex

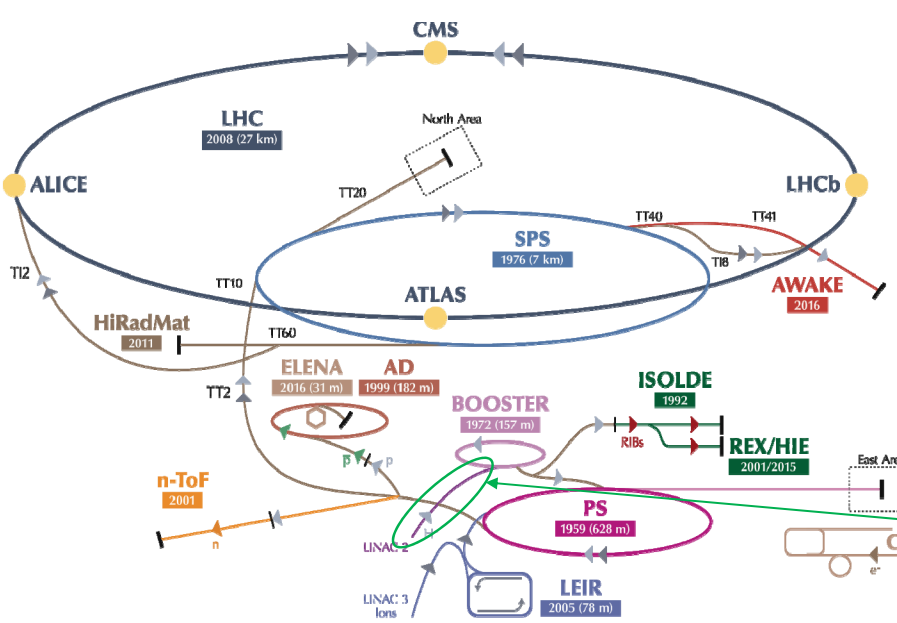


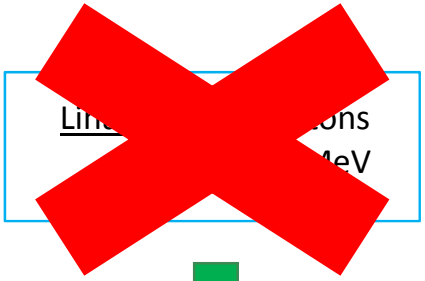


CERN accelerators complex

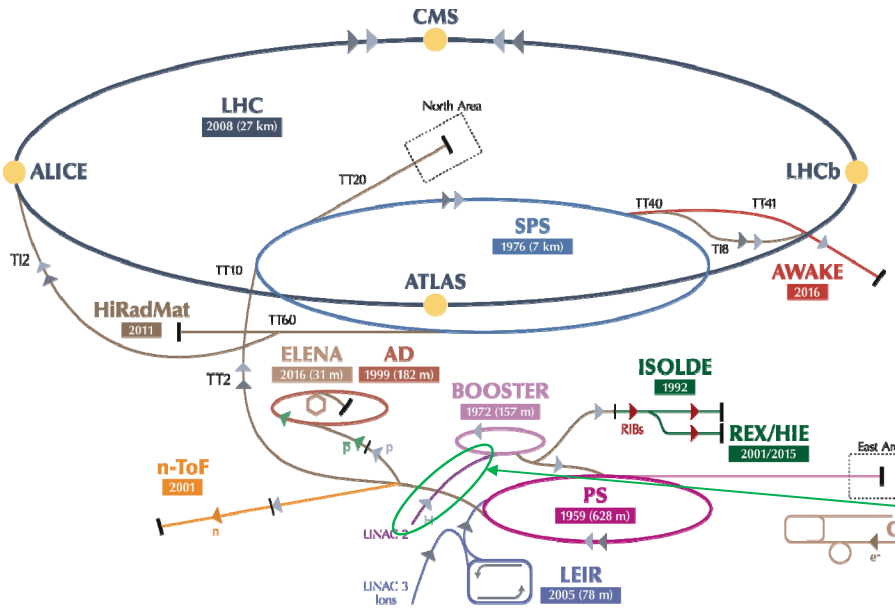


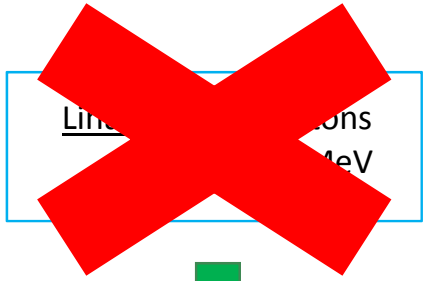
CERN accelerators complex





CERN accelerators complex





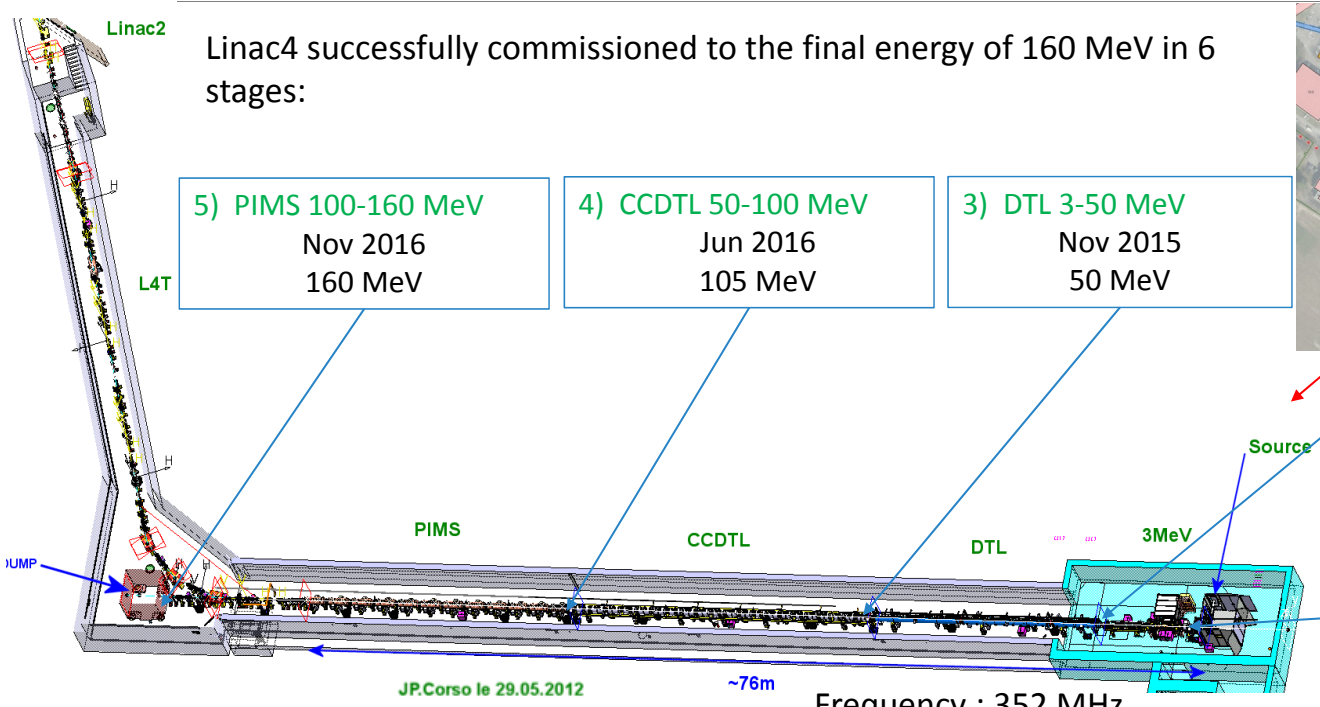
Linac4
- H^-
- 160 MeV

Reduce space charge

Linac4 commissioning

Commissioning

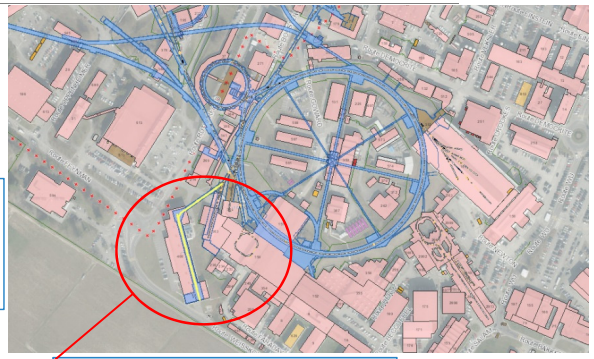
Linac4 successfully commissioned to the final energy of 160 MeV in 6 stages:



5) PIMS 100-160 MeV
Nov 2016
160 MeV

4) CCDTL 50-100 MeV
Jun 2016
105 MeV

3) DTL 3-50 MeV
Nov 2015
50 MeV



2) Preinjector 3 MeV
Oct 2013
3 MeV

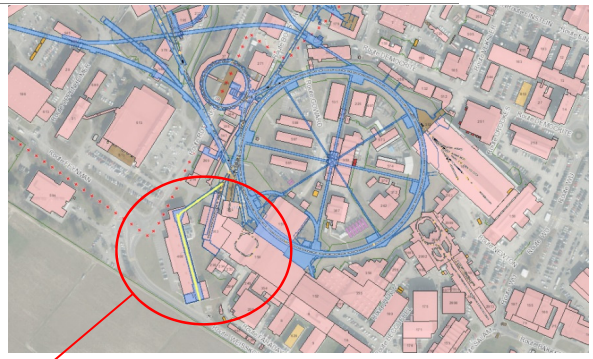
1) Source
Mar 2013
45 keV

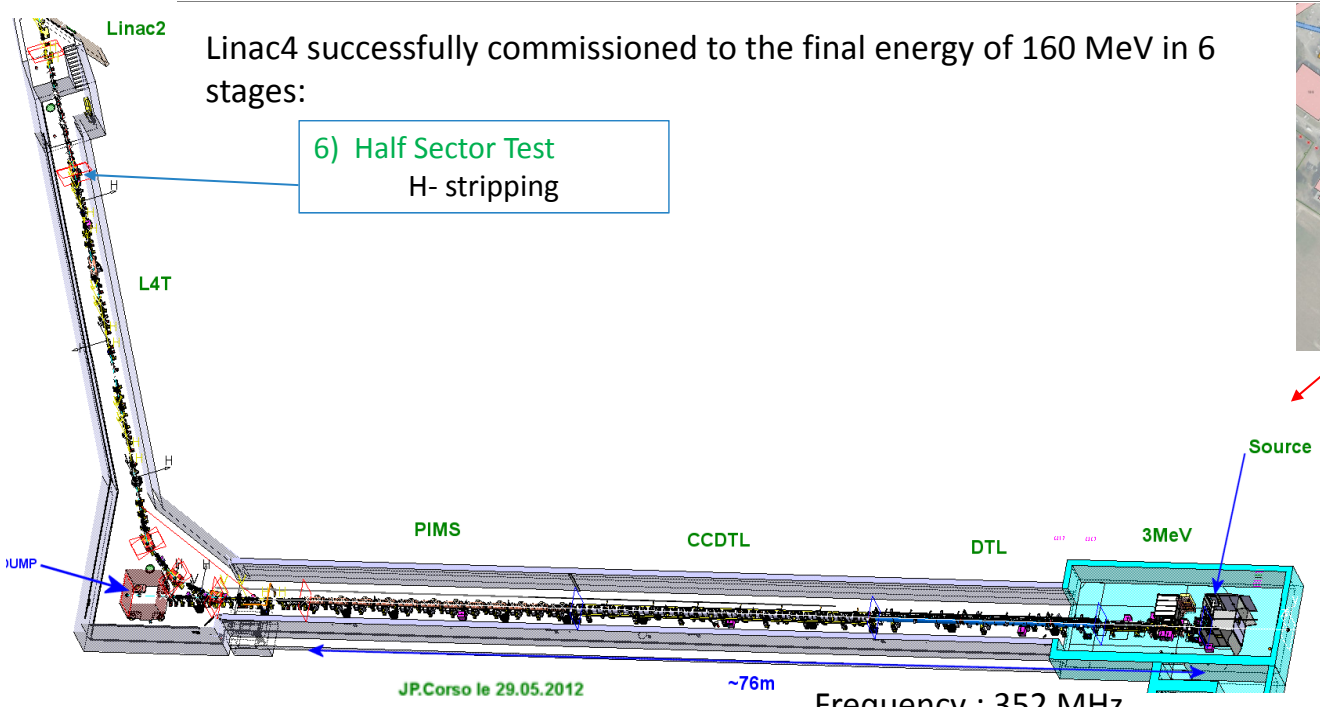
Frequency : 352 MHz

Commissioning

Linac4 successfully commissioned to the final energy of 160 MeV in 6 stages:

6) Half Sector Test
H- stripping

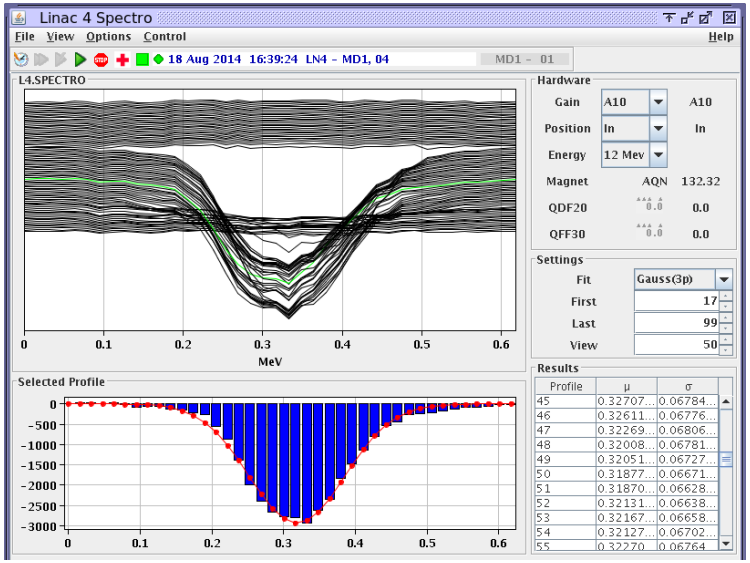




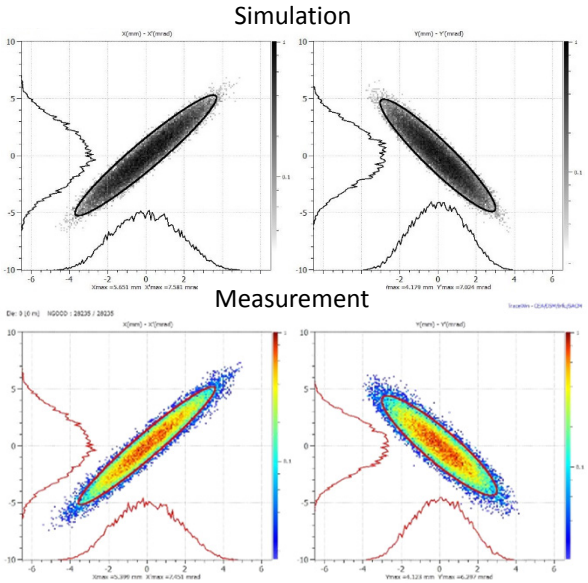
Frequency : 352 MHz

VB5

Beam measurements - some examples



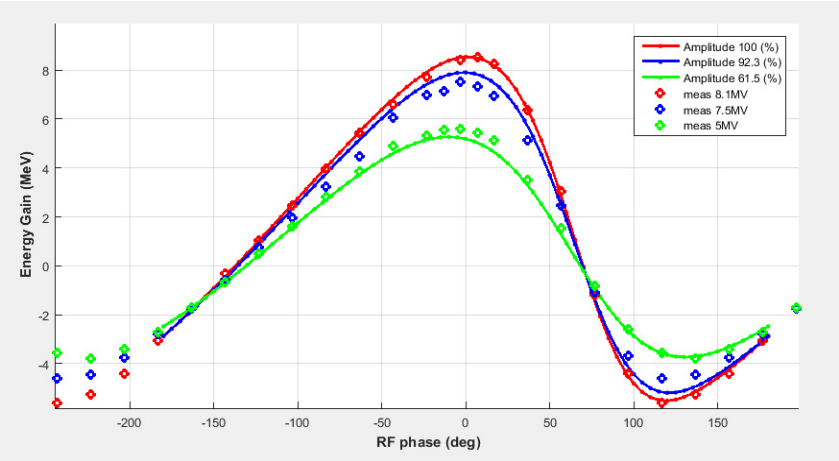
Spectrometer (bending + grid) measurements indicate an rms energy spread of 52.8 keV (vs 49.2 keV expected) after DTL tank1,12MeV, August 2014



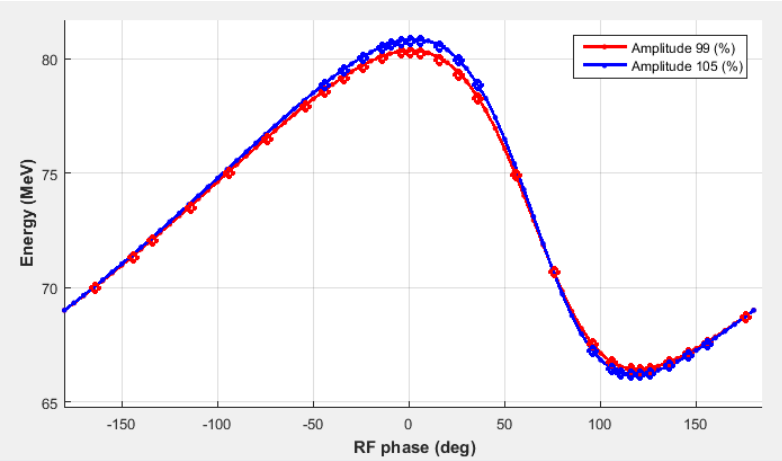
Transverse emittance at 50 MeV after the Drift Tube Linac, Nov 2015

VB6

Beam measurements - some examples



Beam loading



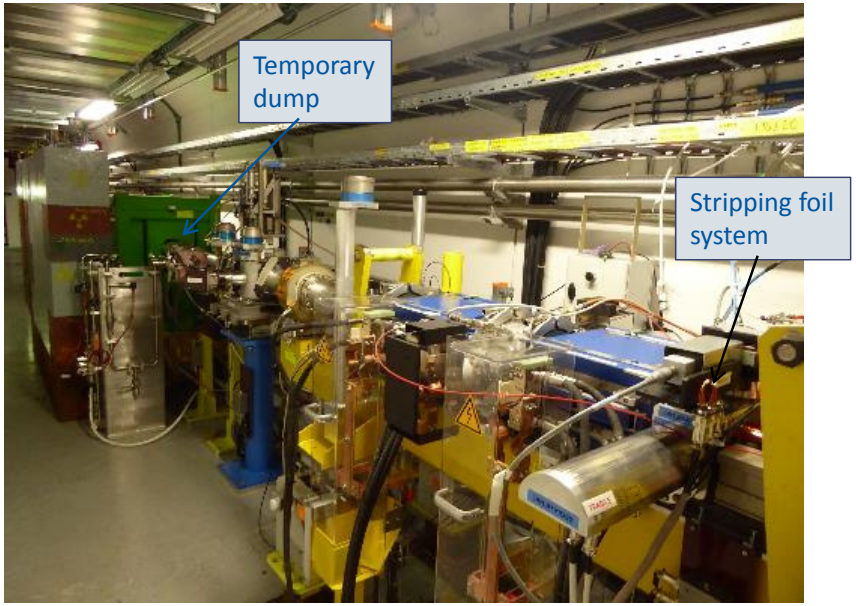
Time-of-Flight

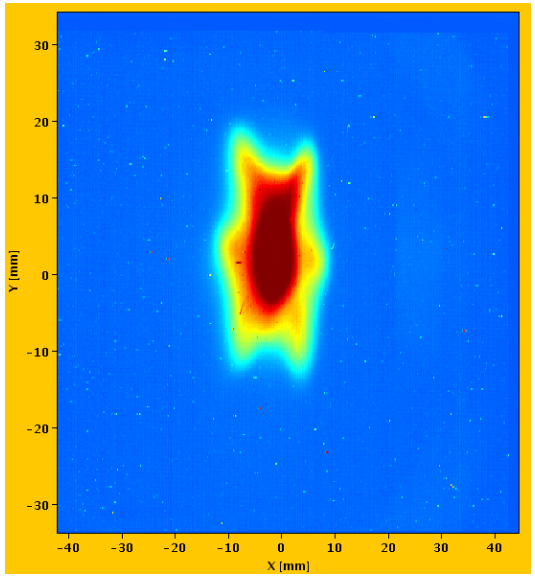
Average energy vs cavity phase for a CCDTL module measured June 2016 with Time-of-Flight and beam loading

Very good agreement between measurements and simulations!!

Beam measurements - some examples

Proton beam after stripping at 160 MeV measured in Half Sector Test





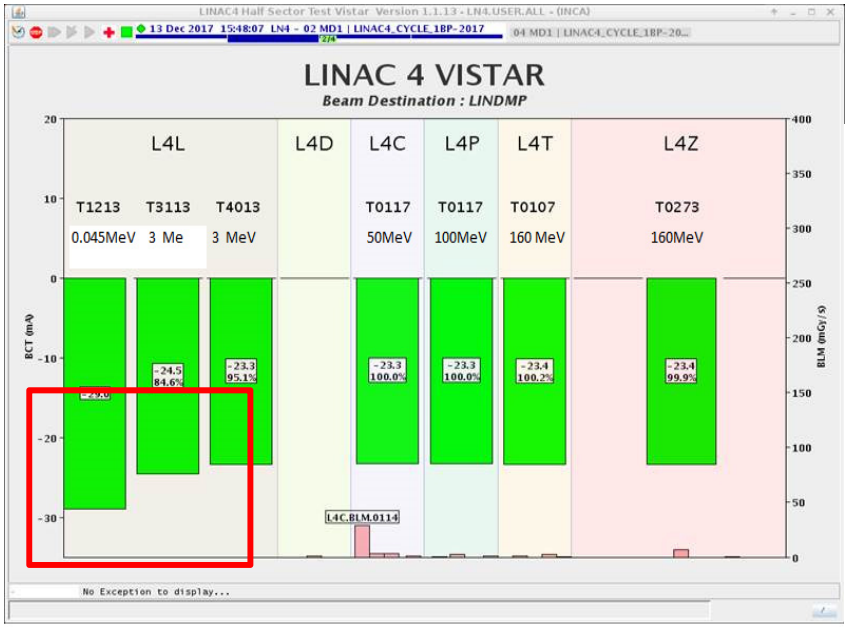
Proton beam transverse footprint – stripped – 160 MeV at , Mar 2017

VB3

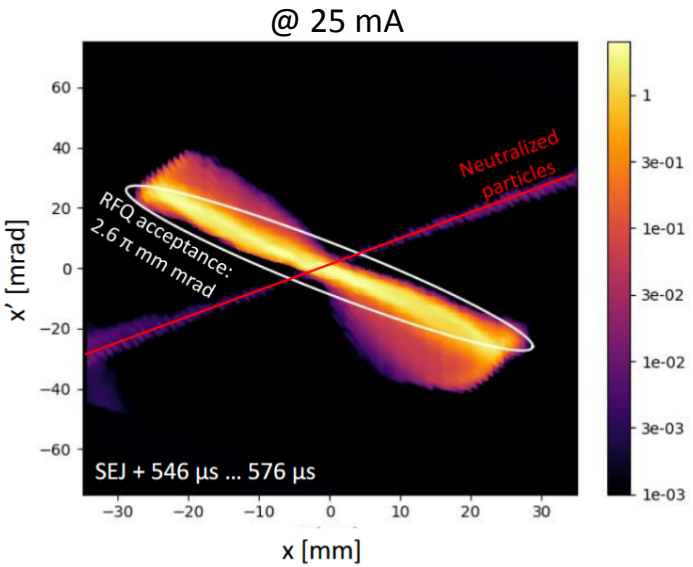
Commissioning achievements

	LINAC4 – CDR -2006	LINAC4 – achieved	
Final energy	160 MeV	160 MeV	All RF structures performing to specs
Stripping	H- stripping	Stripping and more tested in Half Sector Test	
Emittance transv. RMS norm (@ 160 MeV)	0.4 π mm mrad	0.3 π mm mrad	Smaller emittance , allows for more turns injected
Pulse length	400 µsec 1Hz (4 rings)	Up to 600 µsec 1Hz	Longer injection in the PSB (100-150turns)
Chopping system	Fast Chopping at 3 MeV 2µsec inj kicker rise-time	Demonstrated , including transmitted beam quality	- Unprecedented flexibility, to be exploited - Beam from 1µsec to 150µsec
Current	-70mA peak at the source -65 ma peak at 3 MeV -40 mA after chopping	-50mA peak (in twice the acceptance of the RFQ) -30 mA peak at 3 MeV (record) -20 mA after chopping	- Peak current from the source - Average beam current after chopping (LEBT and RFQ transmission and chopping factor)

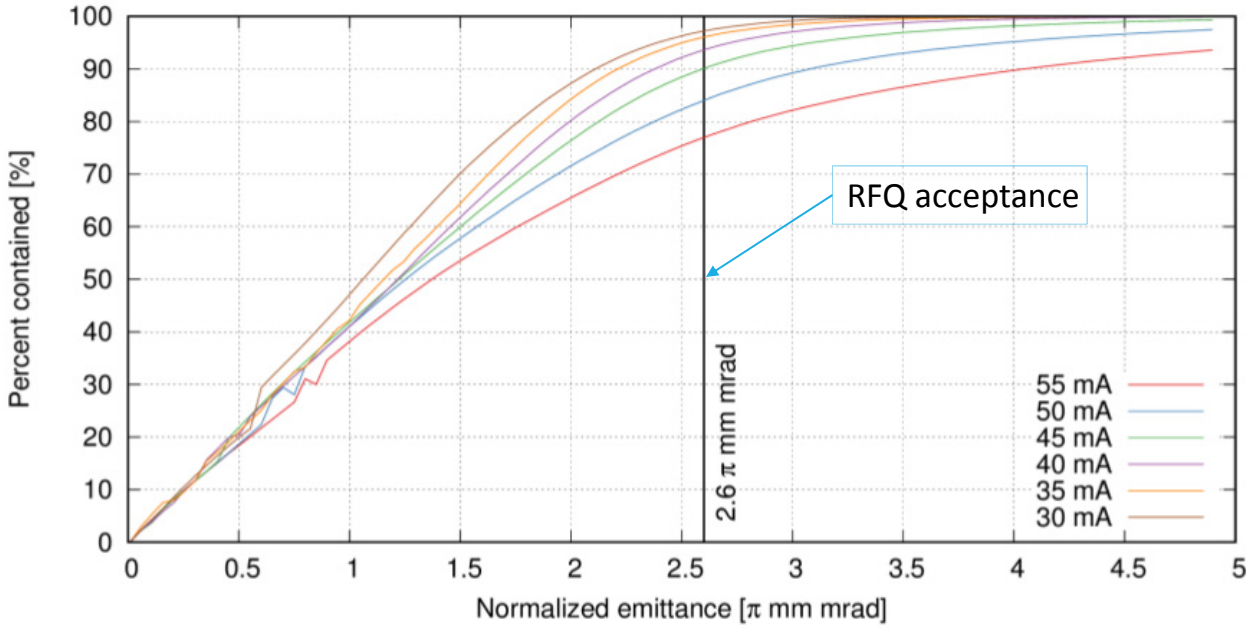
Current limitation – What is the cause?



The main limitations to the peak current and to the beam stability come from the source



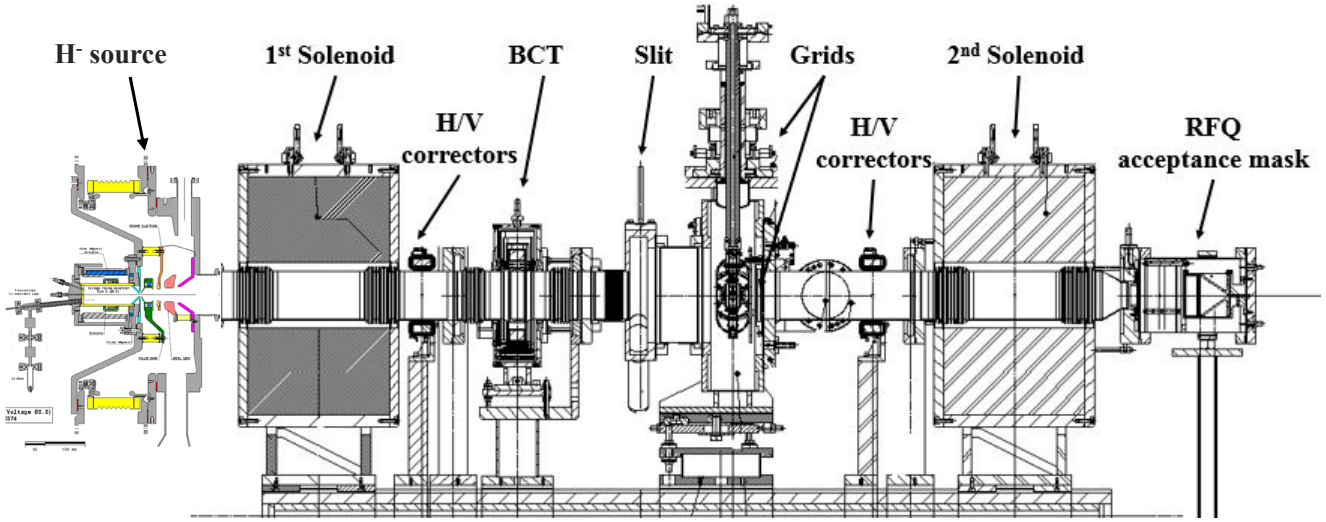
Current limitation – What is the cause?



VB7

Current limitation – Finding a solution

Studies on the Linac4 source Test Stand to overcome the present limitations



- Same configuration present in Linac4 tunnel
- Allows to test different source settings
- RFQ mask mimics the RFQ acceptance

Current limitation – Finding a solution

The activities at the Test Stand are giving really promising results:

- Better understanding of the influence of source parameters on pulse shape and stability (gas pressure, RF pulse stability,…)
- Influence of the extraction geometries
- Increased beam current into RFQ acceptance (32 mA)
- …work in progress…

VB8

For more details see poster and proceeding (here at LINAC 2018):

Activities at the Linac4 Test Stand (TUPO127)
J.B. Lallement et al.

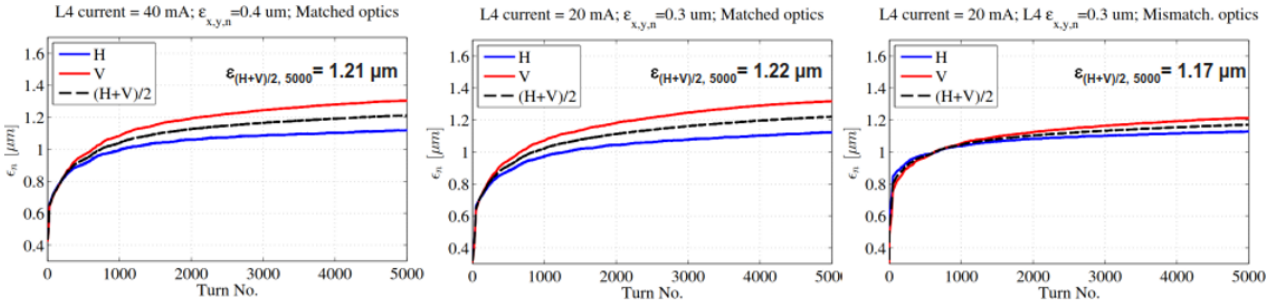
Current limitation – is it enough?

Can Linac4 fulfill the LIU beam requirements with the present performances? VB9

According to simulations (Benedetto/Forte/Bracco) the answer is YES

Requirements	LHC	ISOLDE
Intensity	$3.45 \cdot 10^{12}$ ppr	$0.9/1.2 \cdot 10^{13}$ ppr
Emittance	1.7 µm	10 µm
From Linac4	**LHC**	**ISOLDE**
Current	20 mA	
Turns (or µs @ 1Hz)	30	110/150

5000 turns



Reliability and beam quality run

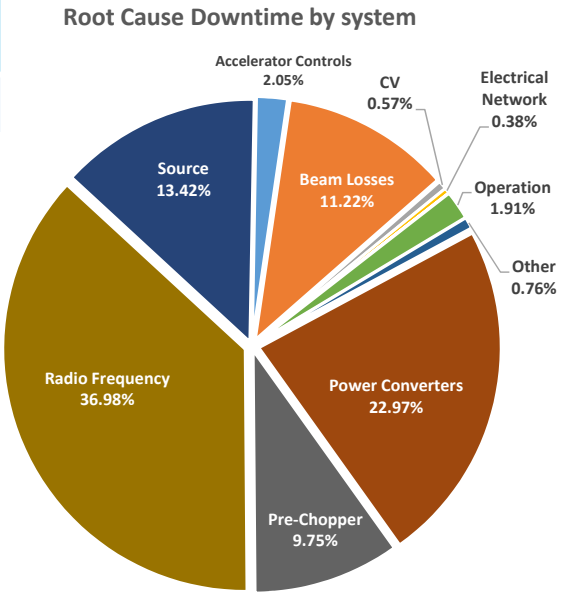
VB10

Reliability and fault tracking

Availability	Fault Count	Operation	Fault Mean Time to Repair
91.5%	**449**	23 weeks	~29 min

- Target reliability: of more than 90%...
  Linac2 availability is 99%!!
- Main downtime cause: RF systems
- Many interventions were performed in the summer to increase the availability (for example RF pick-ups redesign and replacement)

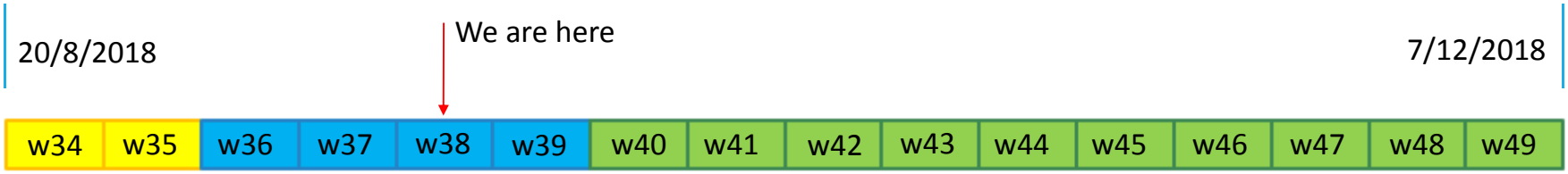
Period: 13/07/2017 – 15/05/2018
Last update: 22/06/2018



A considerable decrease in fault time is expected in the next run

VB11

Timeline for Fall 2018

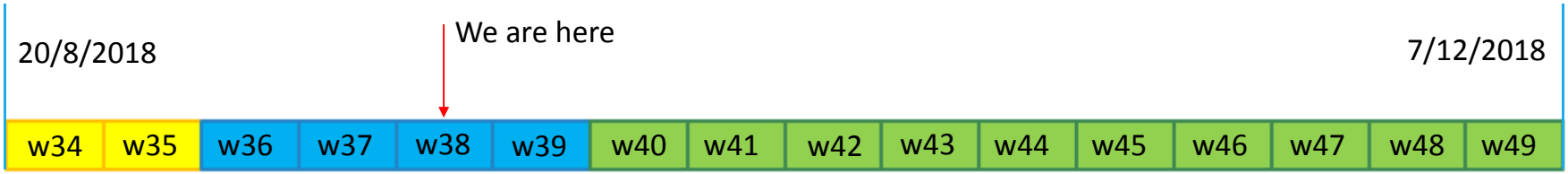


HW commissioning

Beam quality run & RF commissioning

Reliability run

Timeline



HW commissioning

Beam quality run & RF commissioning

Reliability run

Beam quality run

Commissioning phase aimed to reach all the LIU beam quality requirements

VB12

Beam quality run

The goals for the beam quality runs are:

1) Pulse length: 600 µs ✓

2) peak current: 25 mA

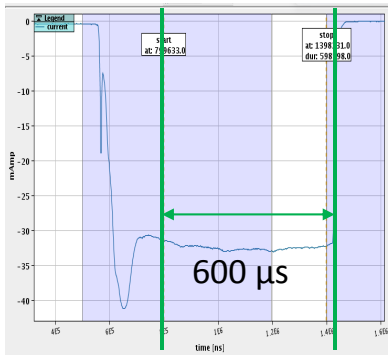
3) pulse flatness: - 5% over 600 µs

- 2% over 120 µs

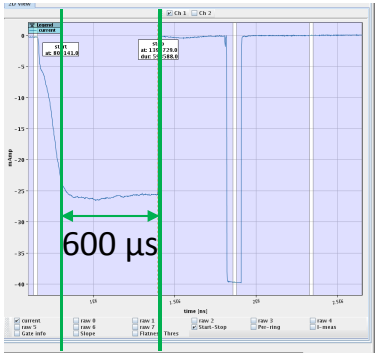
4) Stability shot-to-shot of 2%

Measurements before and after the RFQ show that a stable pulse of 600 µs can be produced

Before RFQ



After RFQ



Beam quality run

The goals for the beam quality runs are:

1) Pulse length: 600 µs ✓

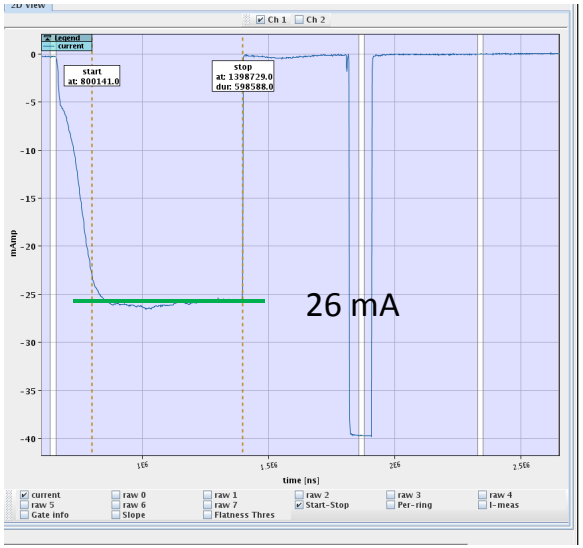
2) peak current: 25 mA ✓

3) pulse flatness: - 5% over 600 µs

- 2% over 120 µs

4) Stability shot-to-shot of 2%

Current above 25 mA after the RFQ is reached



Beam quality run

The goals for the beam quality runs are:

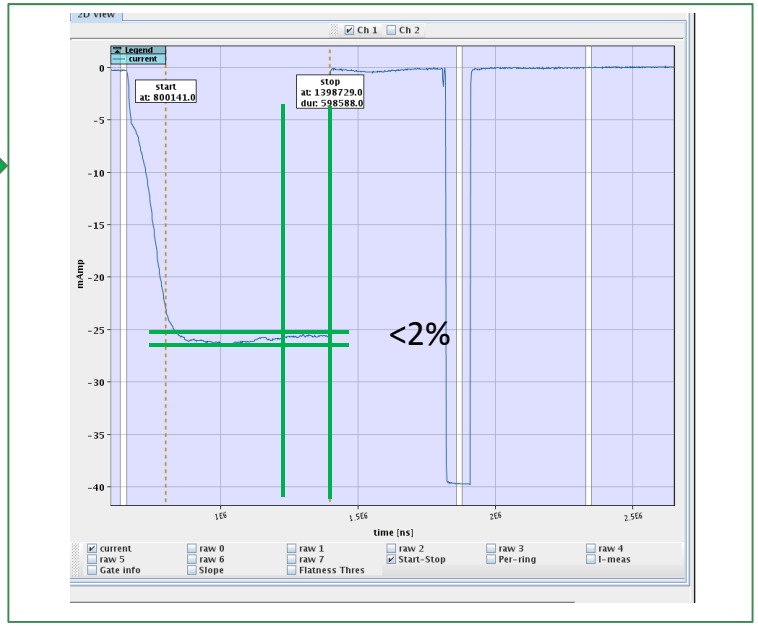
1) Pulse length: 600 µs ✓

2) peak current: 25 mA ✓

3) pulse flatness: - 2% over 120 µs ✓

- 5% over 600 µs

4) Stability shot-to-shot of 2%



Beam quality run

The goals for the beam quality runs are:

1) Pulse length: 600 µs ✓

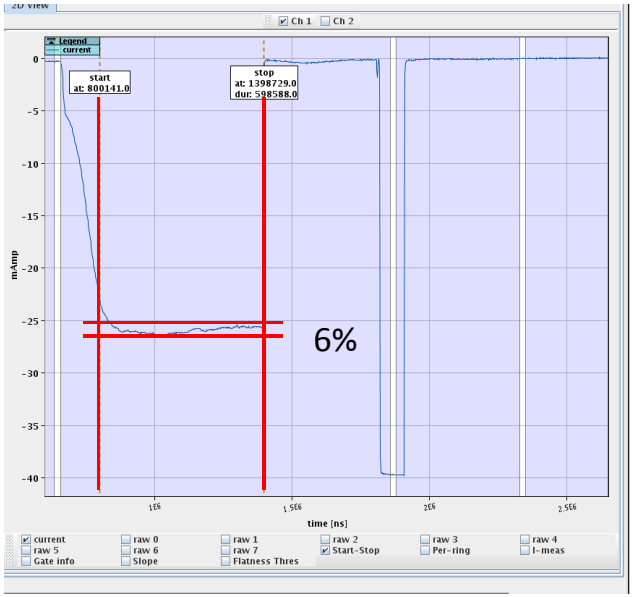
2) peak current: 25 mA ✓

3) pulse flatness: - 2% over 120 µs ✓

- 5% over 600 µs ✗

4) Stability shot-to-shot of 2%

Still not achieved...but almost there



VB13

Beam quality run

The goals for the beam quality runs are:

1) Pulse length: 600 µs ✓

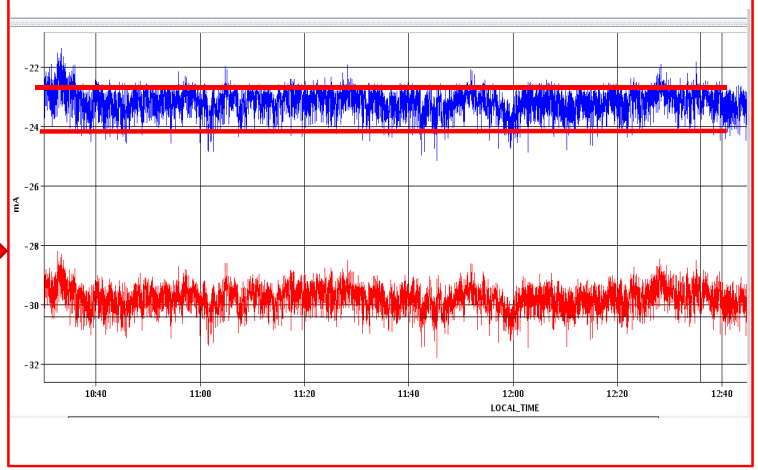
2) peak current: 25 mA ✓

3) pulse flatness: - 2% over 120 µs ✓

- 5% over 600 µs ✗

4) Stability shot-to-shot of 2% ✗

Still not achieved...work in progress



Conclusions and next steps

- Linac4 has been successfully commissioned up to the final energy of 160 MeV and demonstrated to be able to provide the minimum current in the PS Booster needed for the high intensity operations in LHC and ISOLDE
- The reliability run showed that the required availability can be achieved
- Source development at the Linac 3 MeV Test Stand is undergoing to fulfill the nominal LIU beam requirements and to increase the output current

BUT

It's not over until it's connected!

During LS2 Linac4 will be connected to the PS Booster and the transfer line needs to be commissioned.
Much work has still to be done!


Thank you for your attention!
感謝您的關注