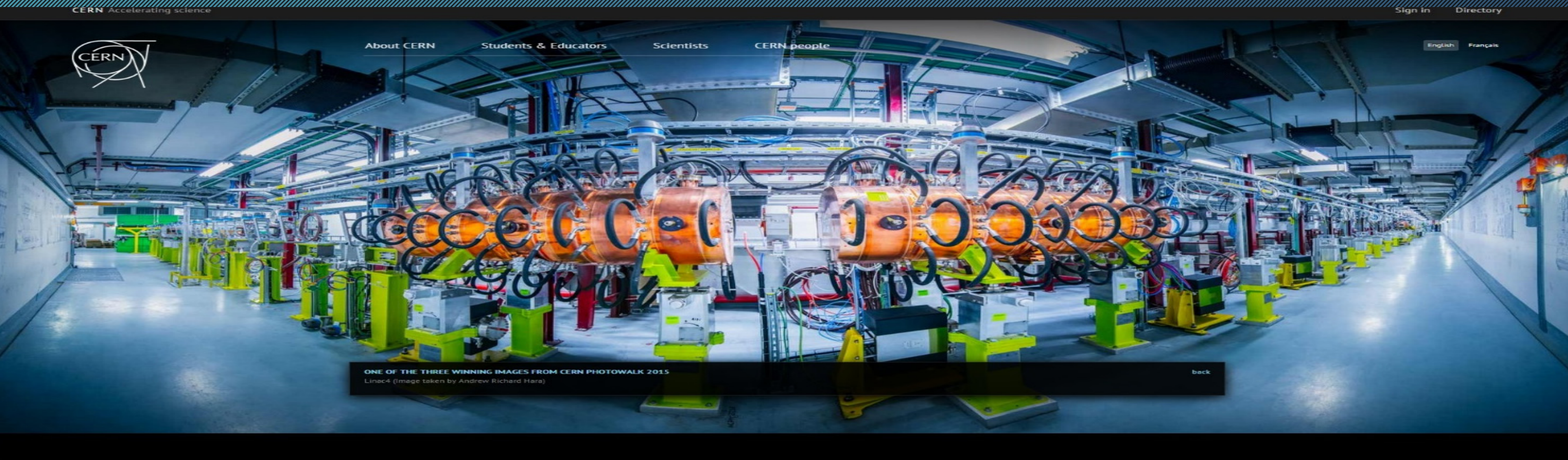
Linac4 Commissioning Status and Challenges to Nominal Operation

G Bellodi for the Linac4 team



61st ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams: Daejeon, Korea, 17-22 June, 2018

Outline of the talk

- Brief introduction & machine commissioning status
- 2017-8 operation:
  - Half Sector Test run
  - Reliability Run
  - Beam quality run
- Beam preparation & open issues
- Conclusions and future planning

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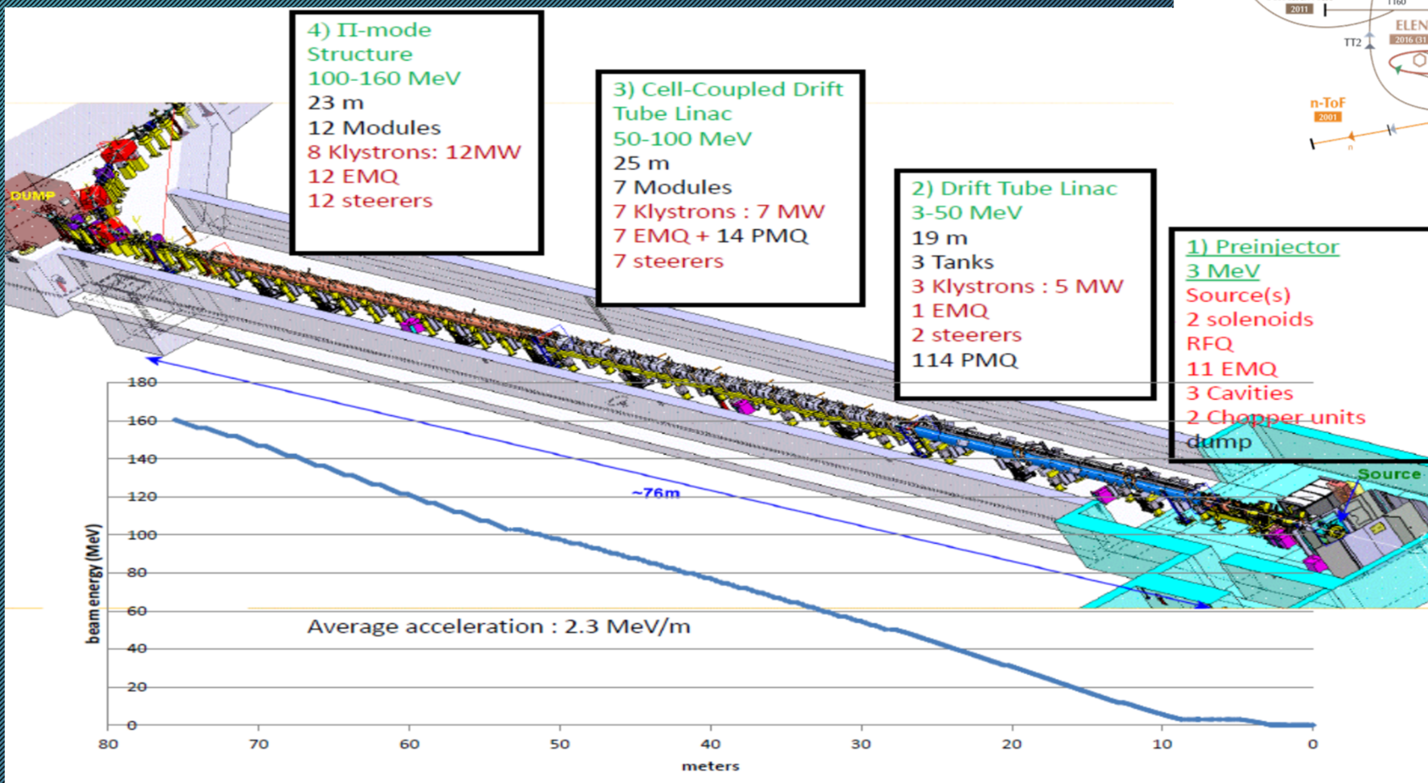
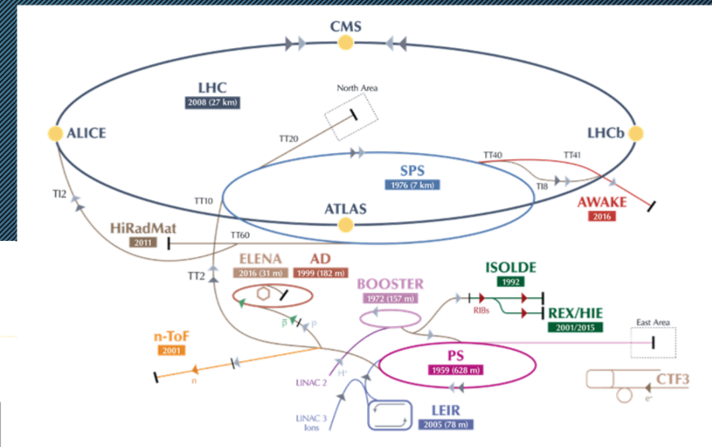
Linac4 sketch and summary details





Commissioning history

Pre-injector (9m)		DTL (19m)		CCDTL (25m)	Π-mode (23m)
3MeV		50 MeV		100 MeV	160 MeV
SOURCE Plasma Generator Extraction e-Dump LEBT 2 solenoids Pre chopper	RFQ CHOPPER LINE 11 EMQ 3 Cavities 2 Chopper units In-line dump	3 Tanks 3 Klystrons : 5 MW 1 EMQ 114 PMQ 2 steerers		7 Modules 7 Klystrons : 7 MW 7 EMQ + 14 PMQ 7 steerers	12 Modules 8 Klystrons: 12MW 12 EMQ 12 steerer
Beam Commissioning stages & achievements					
45 keV	3 MeV	12 MeV	50 MeV	105 MeV	160 MeV
2013 test-stand 50 mA peak current	Completed end 2015 Chopping validated 30 mA peak current	November 2015 24 mA peak current	November 2015 24 mA peak current	June 2016 24 mA peak current	October 2016 24 mA peak current

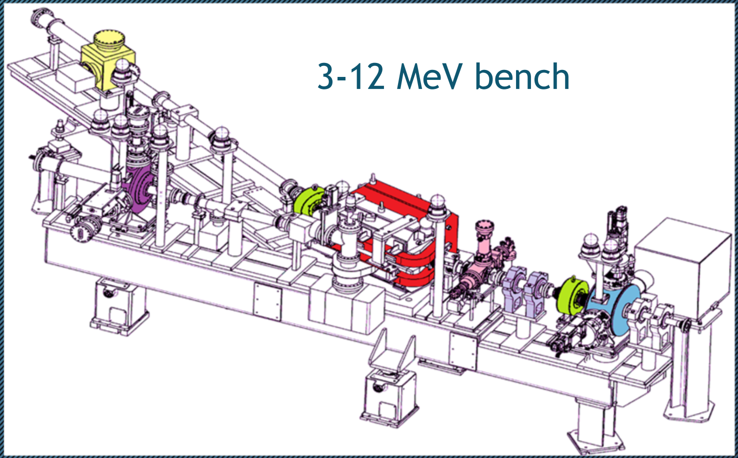
Commissioning diagnostics

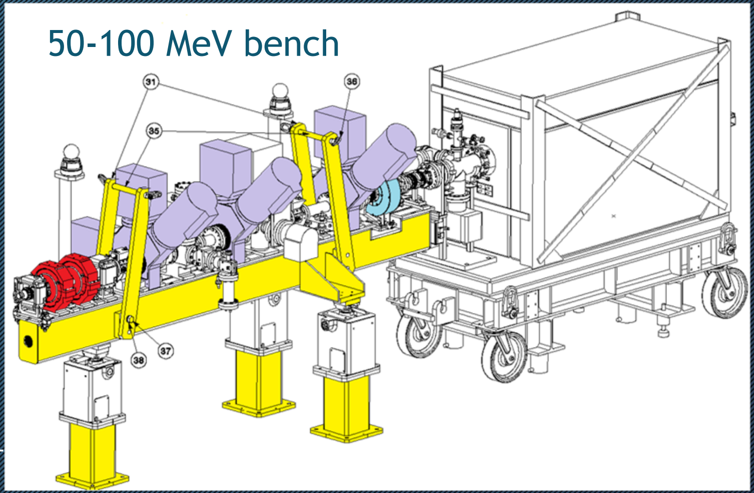
Low energy test bench at 3 and 12 MeV
Direct measurements
- Transverse emittance with slit-grid
- Energy - Energy spread with a spectrometer

High energy test bench at 50 and 107 MeV
Indirect measurements
- Transverse emittance with 3 profile monitors
- Longitudinal emittance with bunch shape monitor

Energy with Time of Flight

Permanent measurement line in the transfer line for 160 MeV





Commissioning key points

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Hardware installation periods alternated with beam validation campaigns (3 weeks long on average)

Systematic measurements and simulations at low energy to characterize input beam distribution are critical for later success

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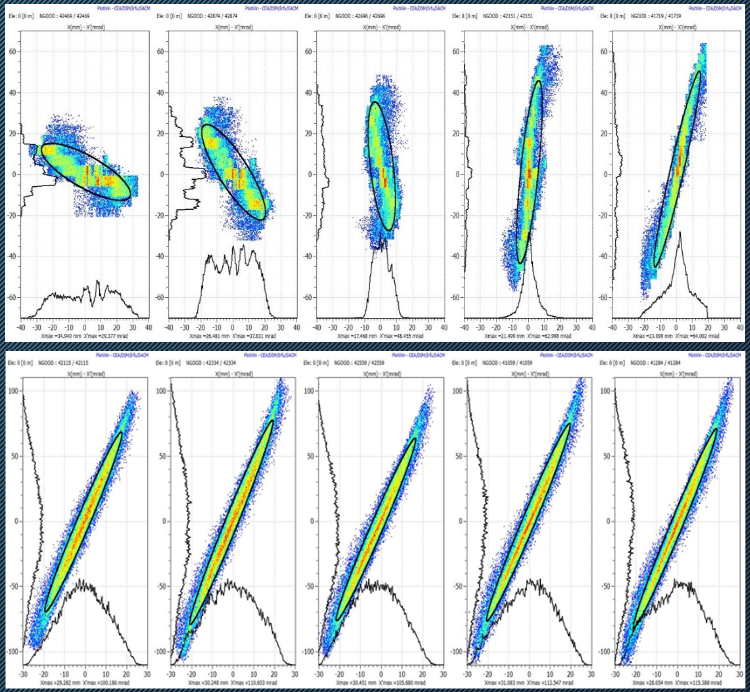
Measurements varying solenoidal field & generate beam distributions

Back-track to the source output



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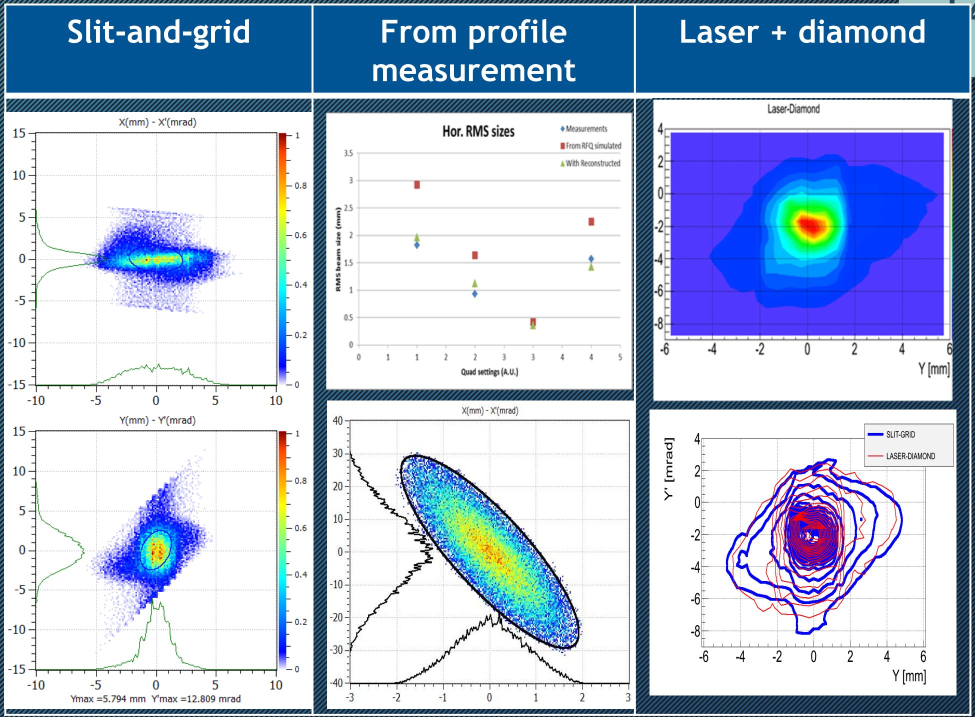

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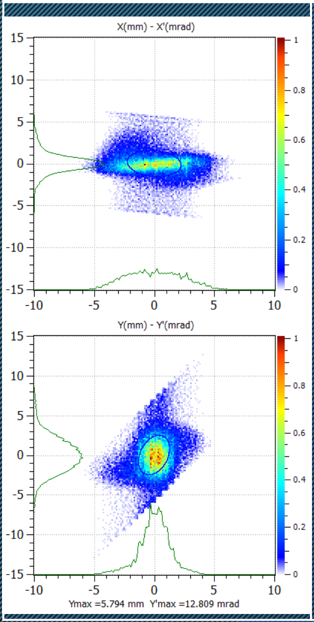
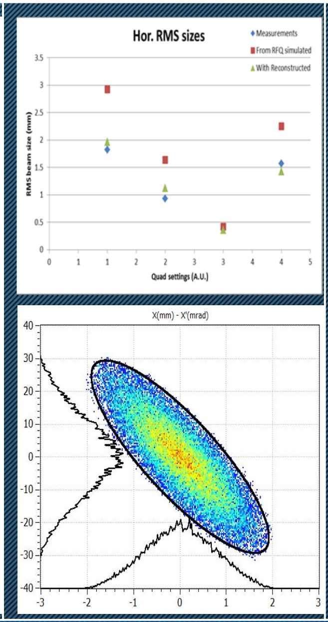
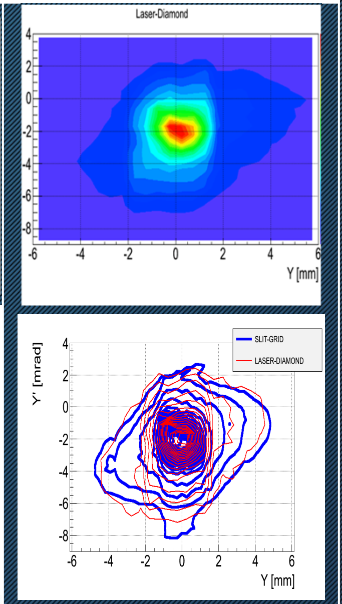
Slit-and-grid	From profile measurement	Laser + diamond







rms normalised transverse emittance @ 3 MeV measured by 3 independent systems:

0.3 π mm mrad

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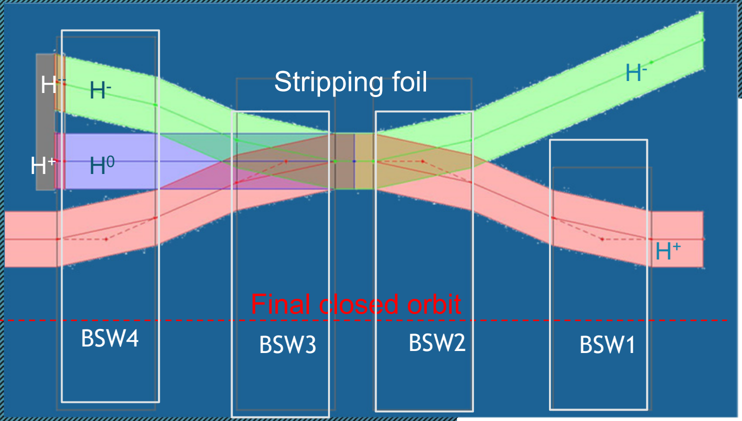
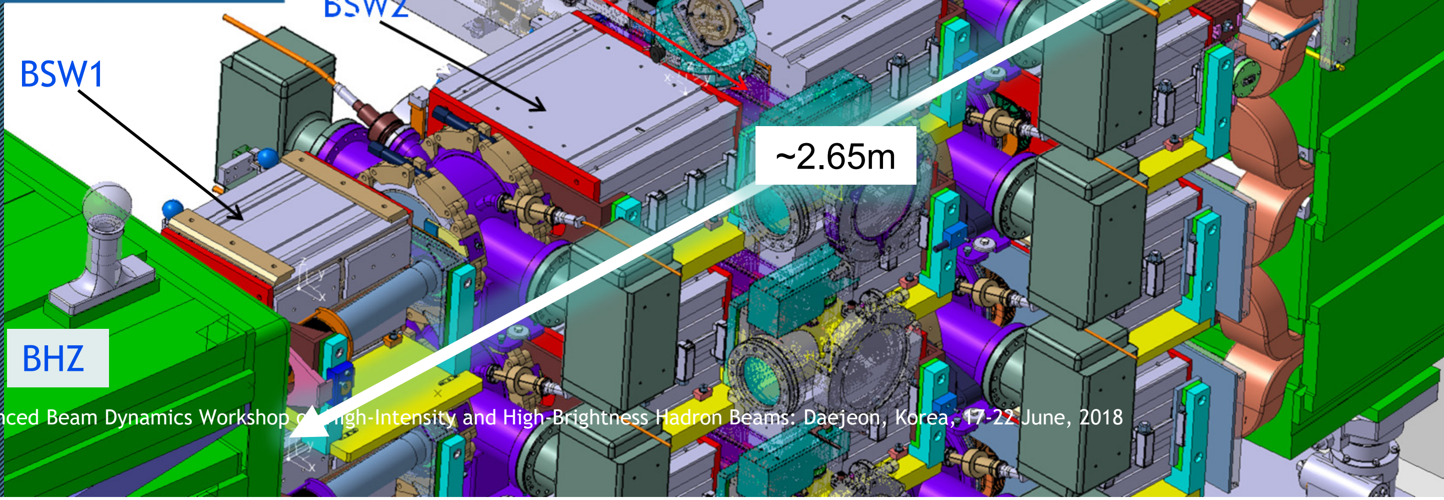
New PSB injection

- Injection of 160 MeV H- beam
- charge exchange injection (no experience at CERN)
- extremely compact and complex installation

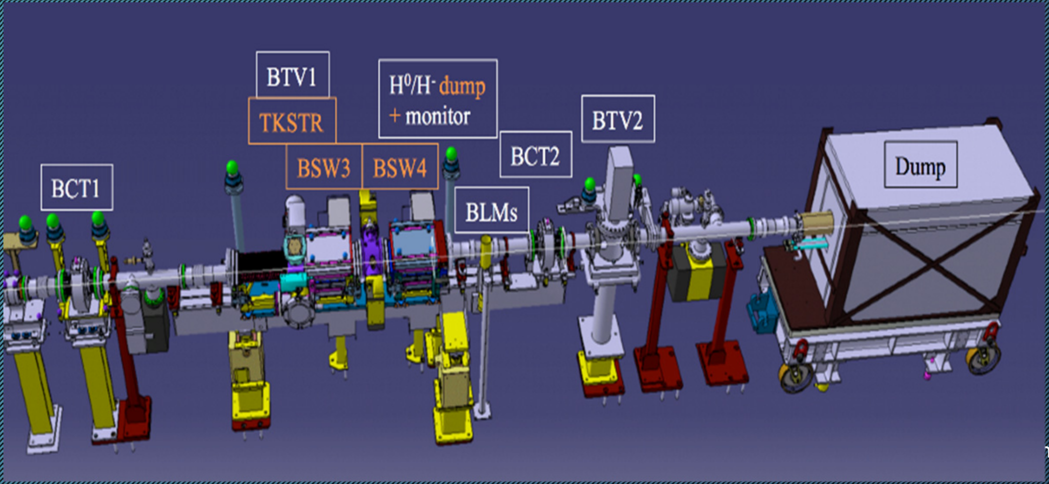




Half sector test run (Oct 2016→April 2017)

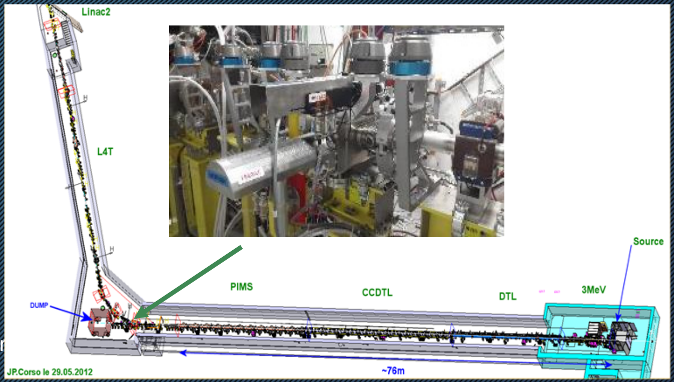
Half of the PSB injection chicane of one PSB ring was installed for tests in the Linac4 transfer line:

- Reduce the risks of installation problems
- Avoid commissioning delays
- Ensure that the new equipment works according to specification



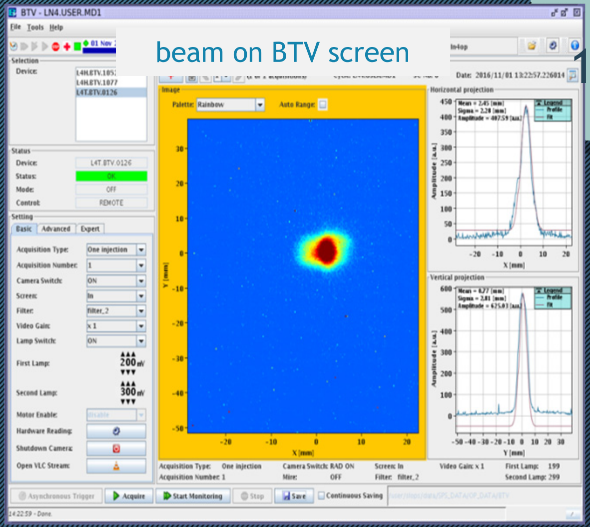
A stripping foil test stand was installed in the Linac4 transfer line allowing tests with a 160 MeV H^- Linac4 beam:

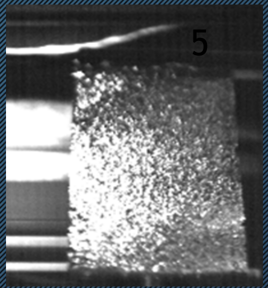
- Testing of foil changing mechanism and interlocking functions
- Gain experience with very fragile foils
- Test different foil materials and thicknesses
- Evaluate the lifetime of the foils and foil holders



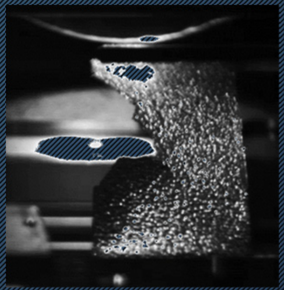
Half Sector Test results

- First stripping efficiency measurements could be performed, which confirmed the expected >99% for 200 µg/cm2 thick Carbon based foils fulfilling the design specifications.
- All the main functionalities were checked and validated.
- A few foil breakages were observed due to interference with the screen for beam observation
- The operational experience gained with equipment handling, controls and interlocks was crucial for future PSB commissioning.
- Input was gained on possible design changes and improvements





intact foil



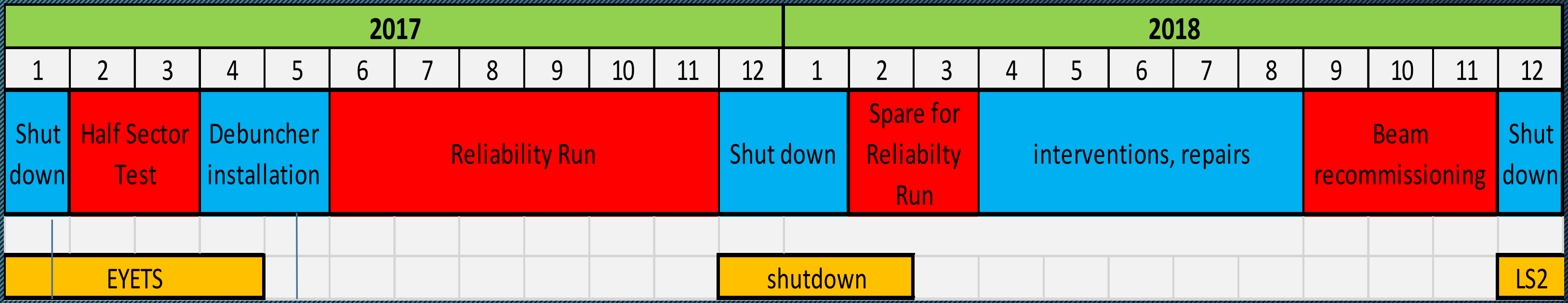
broken foil

Reliability Run (June to December 2017)

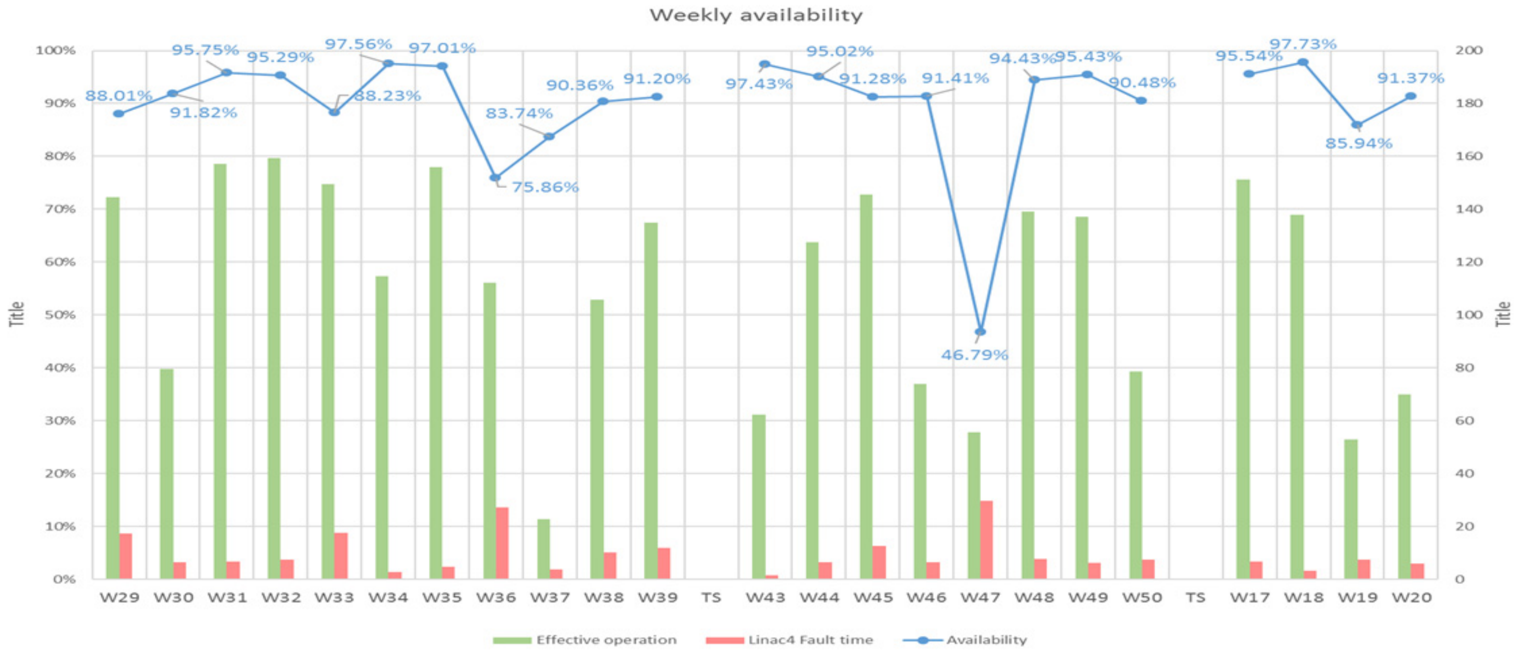
Motivation: >90% availability target (Linac2 now running at 98%)

Goals: consolidation of routine operation thanks to identification of recurring problems & weak points. Gain of operational experience.

Procedure: Linac4 run 24h/7 with faults logging (Accelerator Fault Tracker developed for LHC). Machine availability calculated during working hours after subtraction of scheduled interventions time. Manual stop-clock applied in case of overnight and weekend faults.

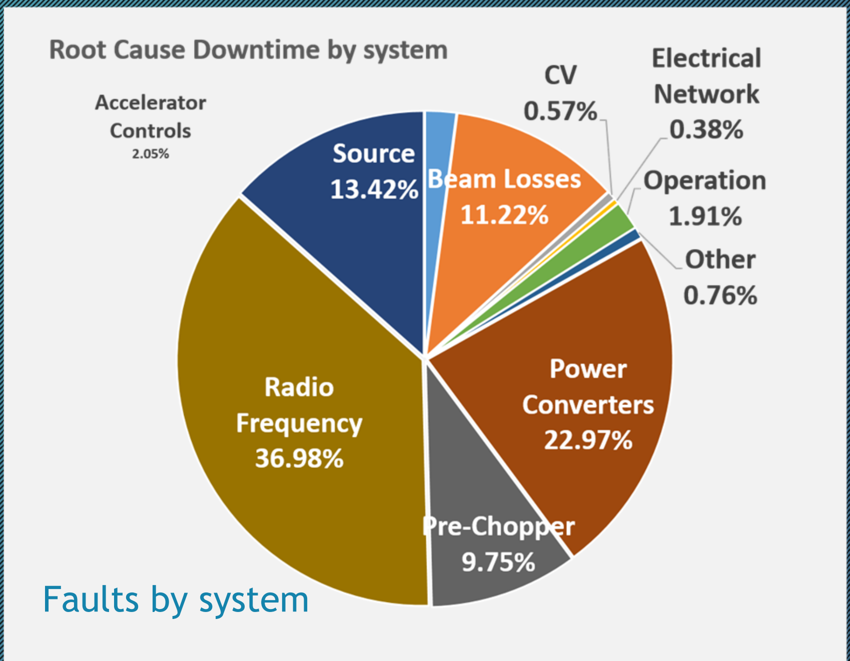


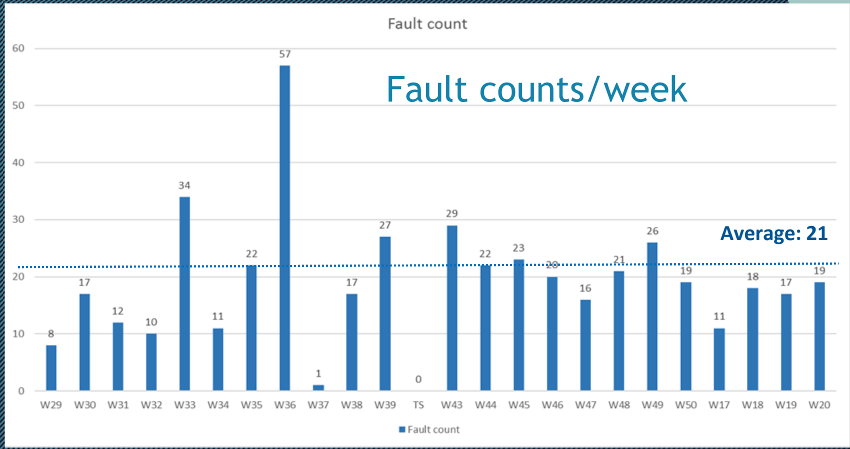
Weekly Reliability 2017 -2018

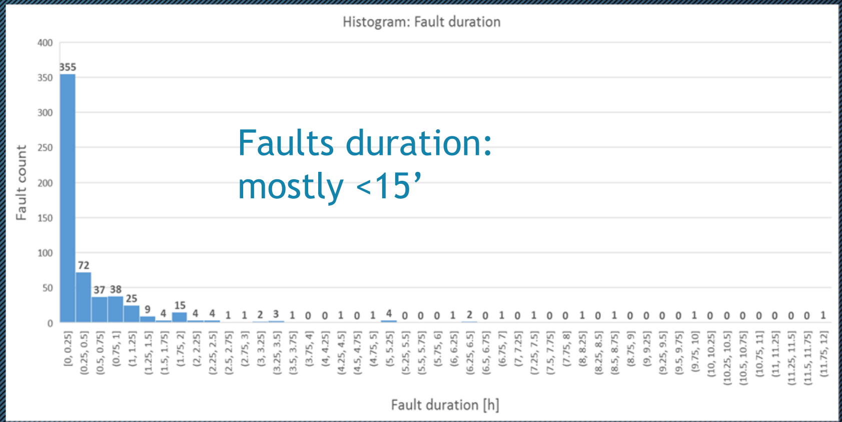


Availability	Fault Count	Operation	Suspended OP	Effective Operation	Fault Mean Time to Repair
91.5%	**449**	23 weeks	~ 8 weeks	~15 weeks	~29 min

Machine faults statistics







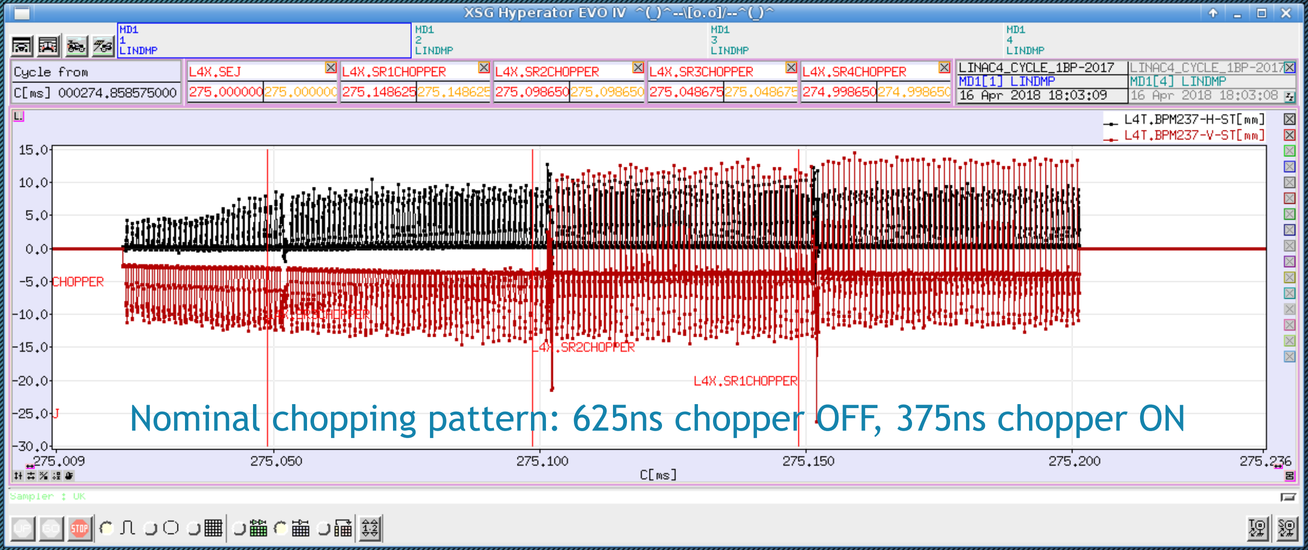
Beam quality run (February→ May 2018)

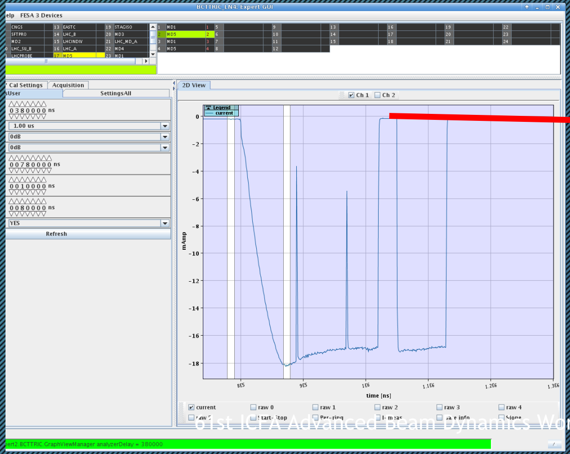
Goal: re-commission the modifications done during YETS 2017-2018 (LLRF and RF restart procedures upgrades etc)

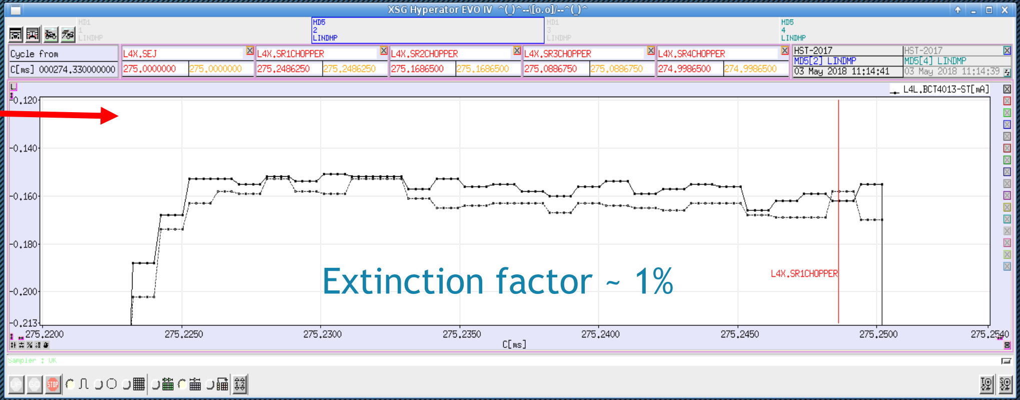
Beam quality measurements to validate PSB requirements:

Min. peak current (before chopping)	40 mA	See later
Intensity flatness along the pulse for pulse lengths up to 160 µs	±2%	For uniform production of LIU LHC beams, Studies for LIU LHC beams are based on flat pulses and 100% transmission.
Intensity flatness along the pulse for pulse lengths >160 µs	±5%	
Horizontal/vertical position variations along the pulse	±1 mm	To comply with target emittances required by LIU LHC beams
Horizontal/vertical injection angle error	±<0.4 mrad	
Current stability shot-by-shot	±2%	
Normalized transverse emittances	≤0.4 mm mrad	
Beam energy	160 MeV	
Ppm energy spread	~80-450 (600) keV	Can be measured only in 2019
Nominal chopper operation/extinguish factor		
Energy painting		Can be measured only in 2019

Chopper performance



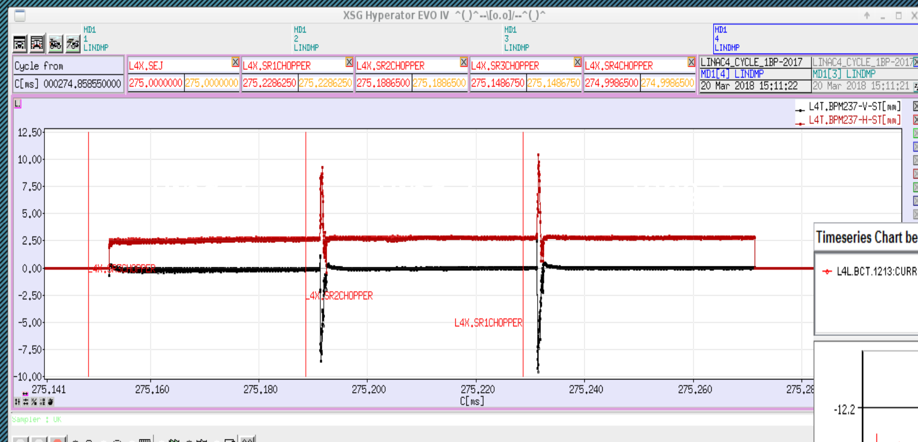




Current/position stability along pulse

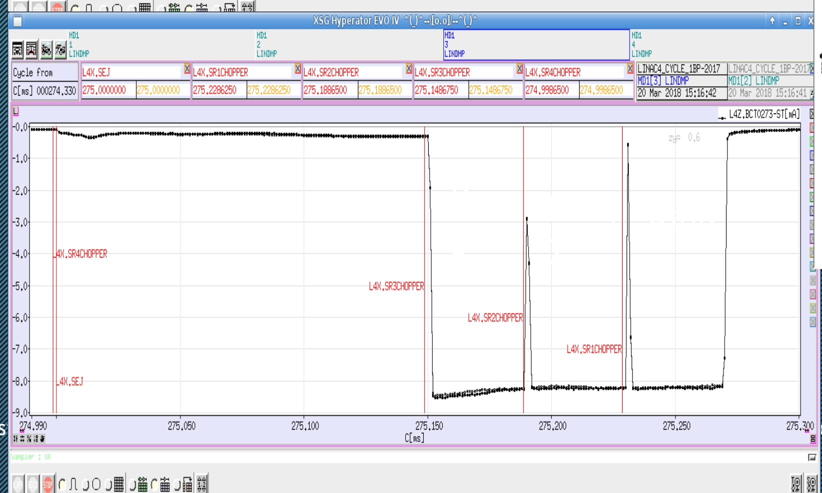
H/V position on L4T pick-up

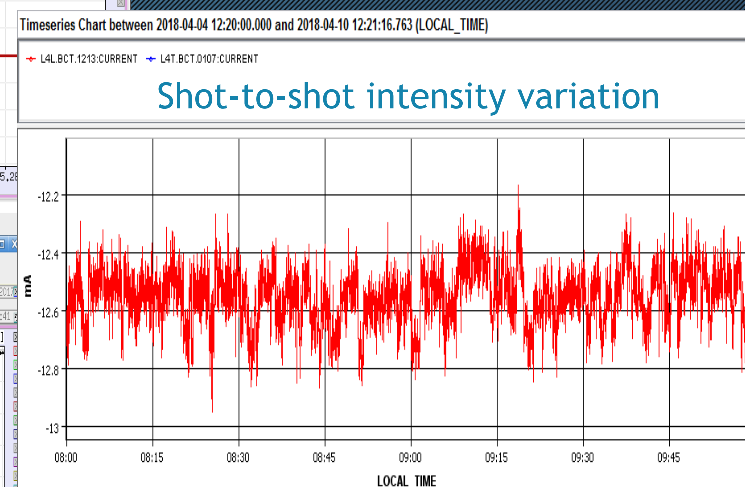
< +1mm



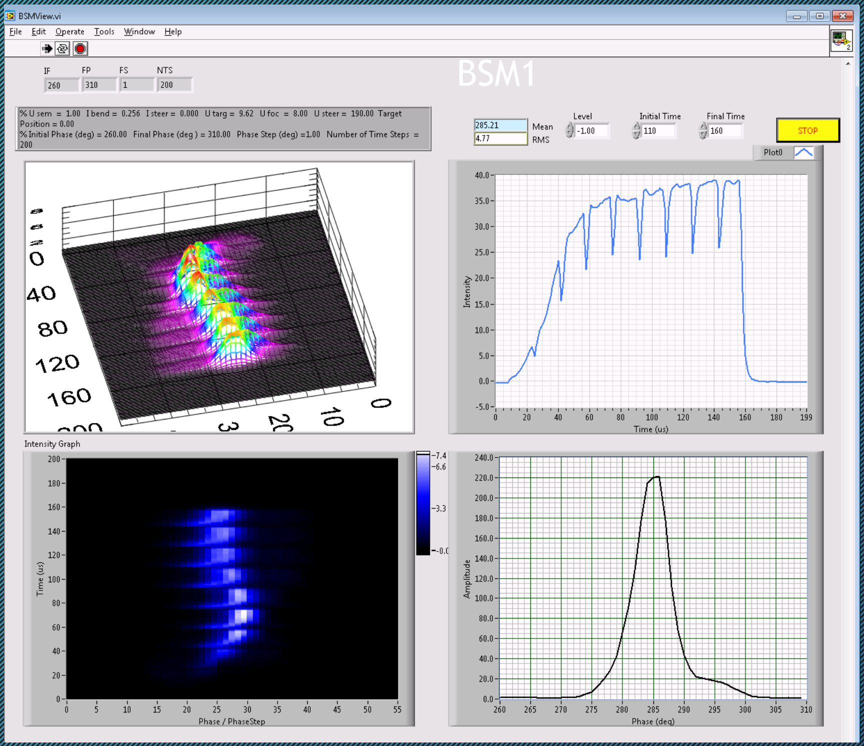
Beam intensity on L4Z BCT (3 rings)

< +-2%

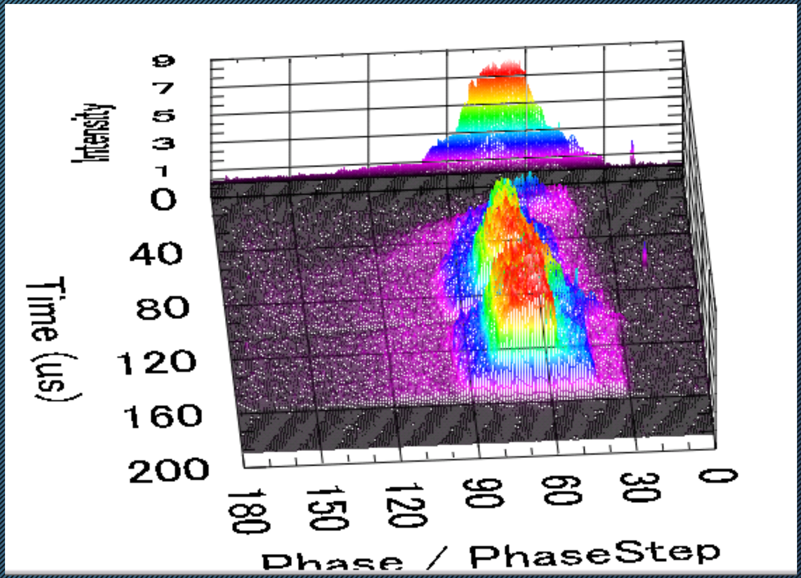




Bunch Shape Monitor at 160 MeV

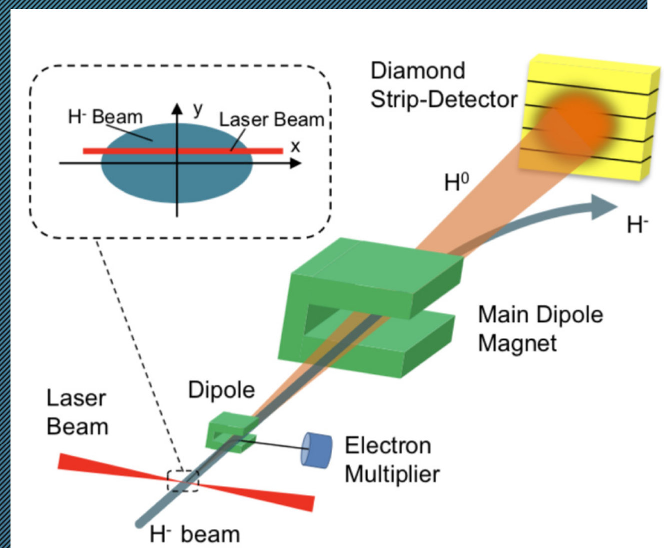


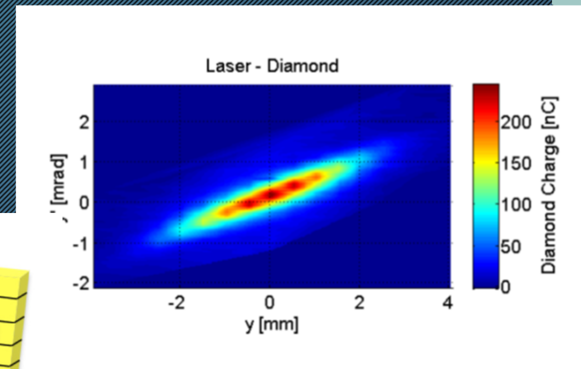
BSM2

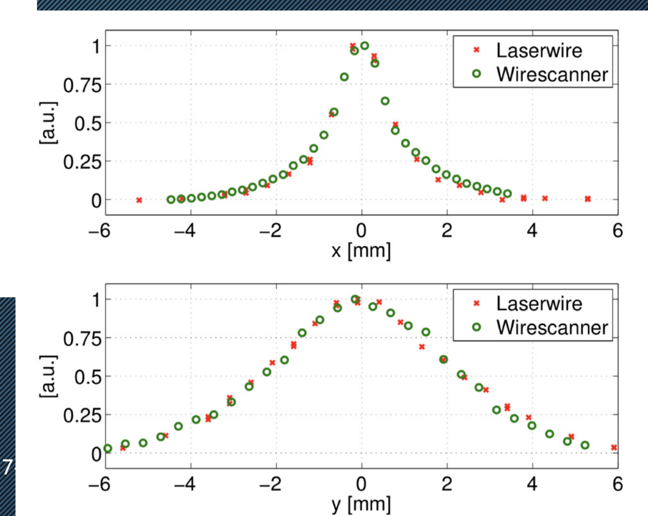


Laser Emittance Meter

- Transverse profile and emittance
- Validated at 3,12,50, 100MeV
- 2 final stations installed and under commissioning
- FESA being finalized
- OP GUI to be developed







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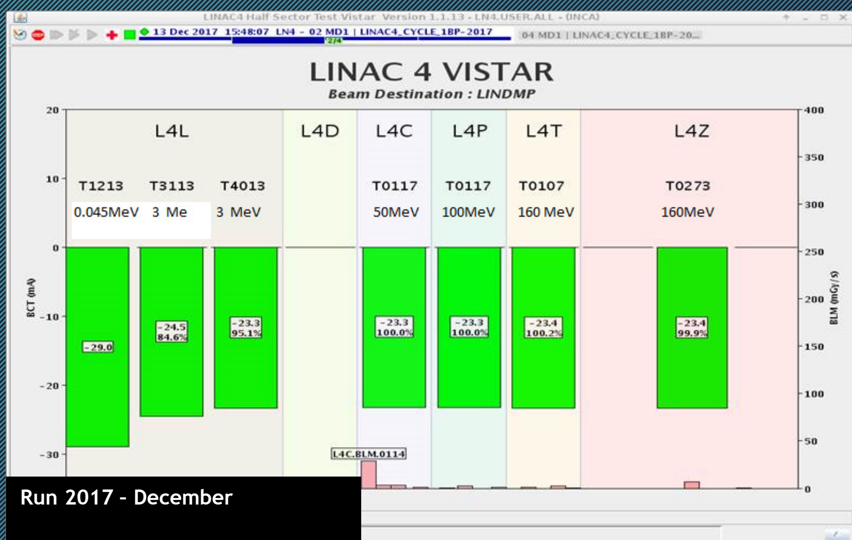
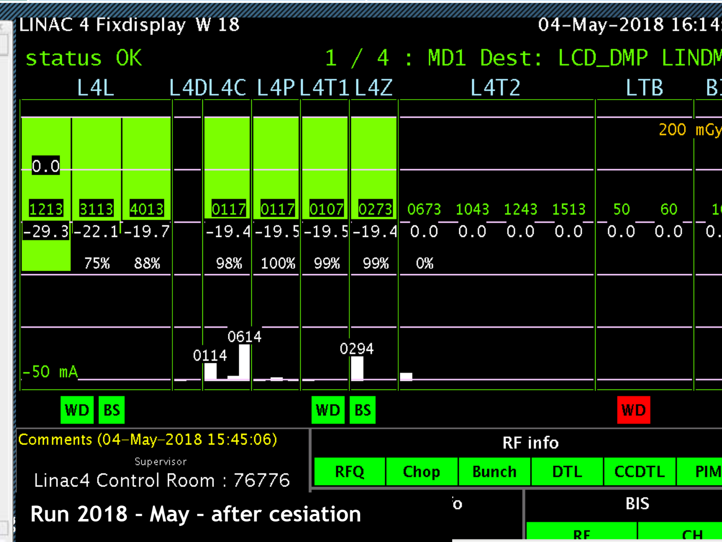
Are we on target?

	Linac4 design targets	Linac4 achieved
Peak current in the linac	40 mA	24 mA
Routine current in the linac	40 mA	20 mA
Transverse emittance at 160 MeV	0.4 π mm mrad	0.3 π mm mrad
Energy at PSB injection	160 MeV	160 MeV
Pulse length / rep rate	400 μs/ 1 Hz	Up to 600 μs/ 1 Hz



Run 2017 - December



Run 2018 - May - after cesiation

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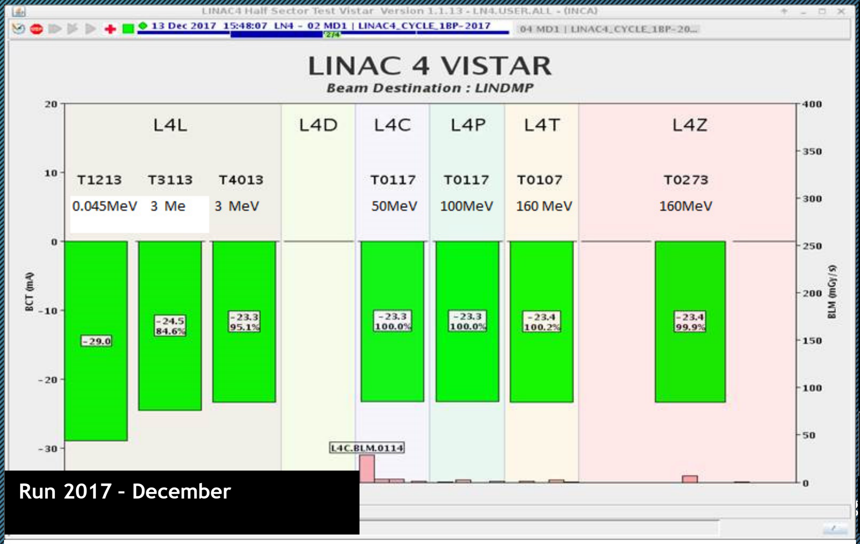
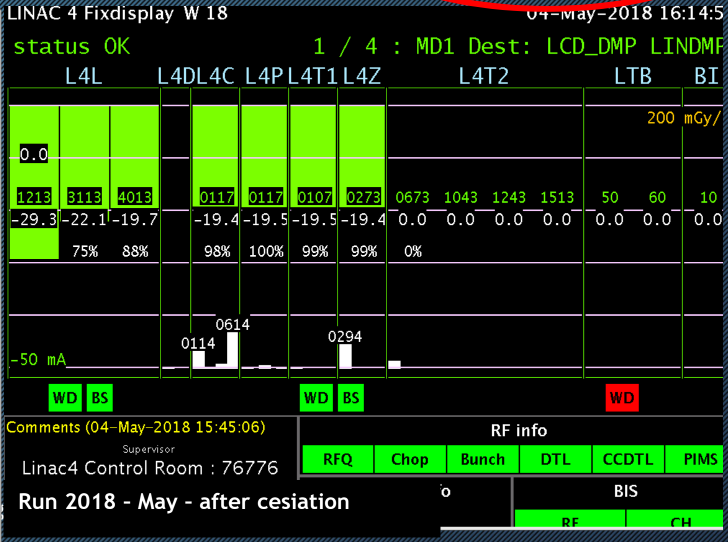
100%





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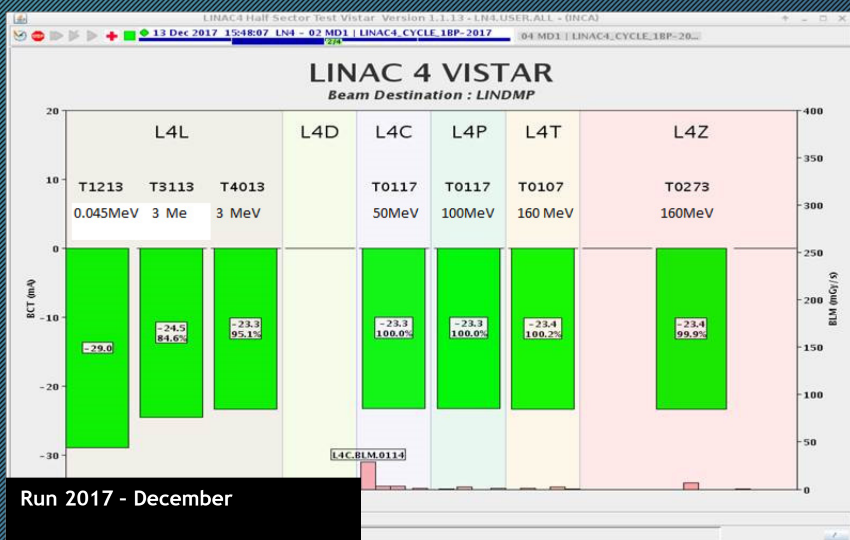
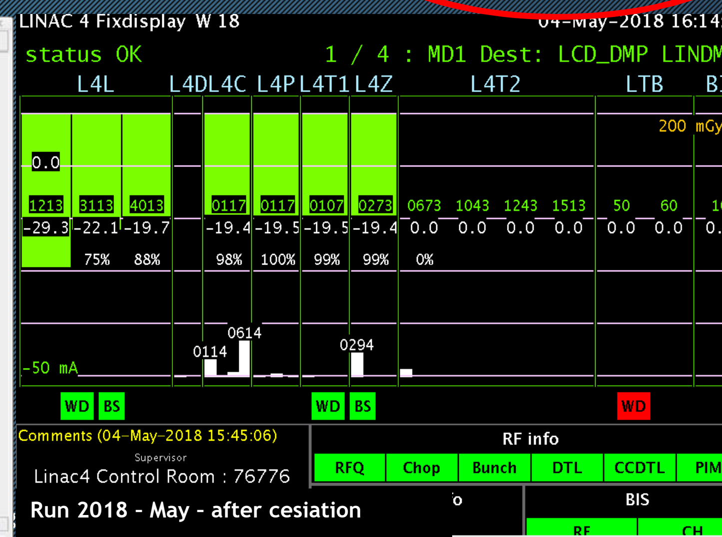
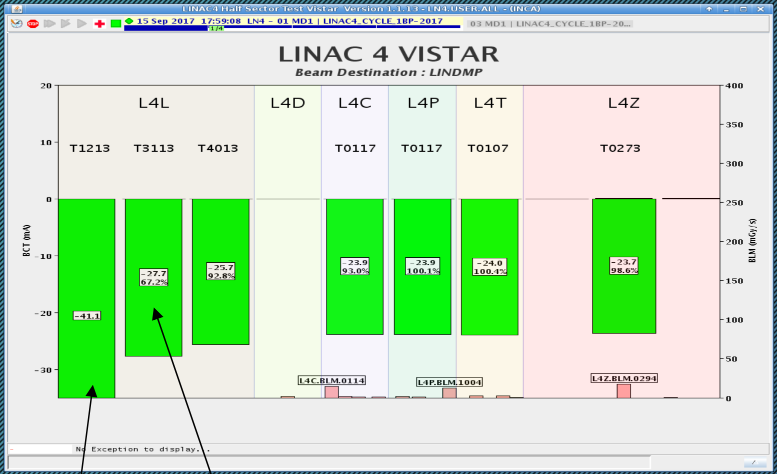
60%

100%



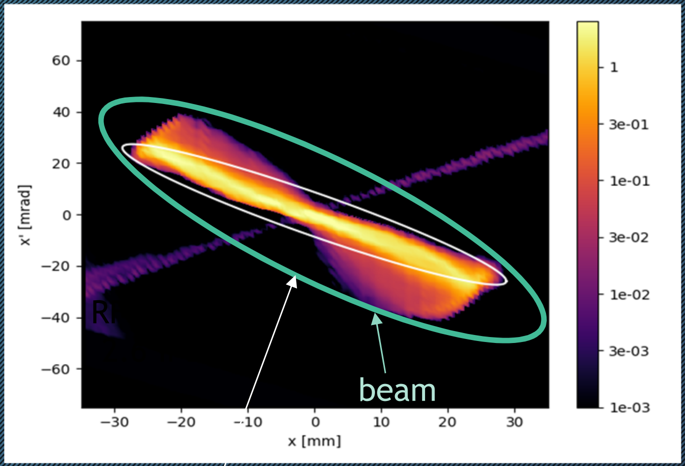


Intensity limitation in the pre-injector



BCT1, before RFQ = 40mA

BCT2, after RFQ = 27mA



Baseline Linac4 source delivers the right beam current in the wrong emittance

Measured emittance (yellow) vs RFQ acceptance (white)

…and ways out of there

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#1 R&D programme on a dedicated ion source test stand to study alternative source extraction geometries and/or different plasma generators. Explore upgrade paths.

#2 Compensate lower intensity by increasing the number of injection turns in the PSB and exploiting the large machine flexibility.
Current performance is sufficient to guarantee LHC-type and fixed target physics-type beams production.

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see also
WEP2PO007

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Beam	Intensity (protons/ring)	Emittance at PSB - [mm mrad]	Nº turns at 20 mA beam current (*)
LHC-type	3.4×10^{12}	1.7	45
Fixed target physics	$1\text{-}1.2 \times 10^{13}$	10	110-150

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(*) at nominal 65% chopping factor

Conclusions

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- Reliability run proved to be a very useful experience, allowing to gain experience on running a complex system, and an early identification of recurrent problems.
- ~90% reliable beam operation on the main dump was achieved
- Measurable beam quality requirements have been demonstrated (stability, flatness, chopper specs etc)
- Transition from commissioning to operation is being detailed and organized

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Coming next

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- Transition from commissioning to operation is being detailed and organized

Coming next

- Extended Technical Stop until September to complete scheduled RF upgrade activities
- Re-commissioning until end of the year
- Connection to the PSB in the first semester of 2019 followed by more re-commissioning periods to complete validating the installation before start of operation in 2021.

Thank you for your attention

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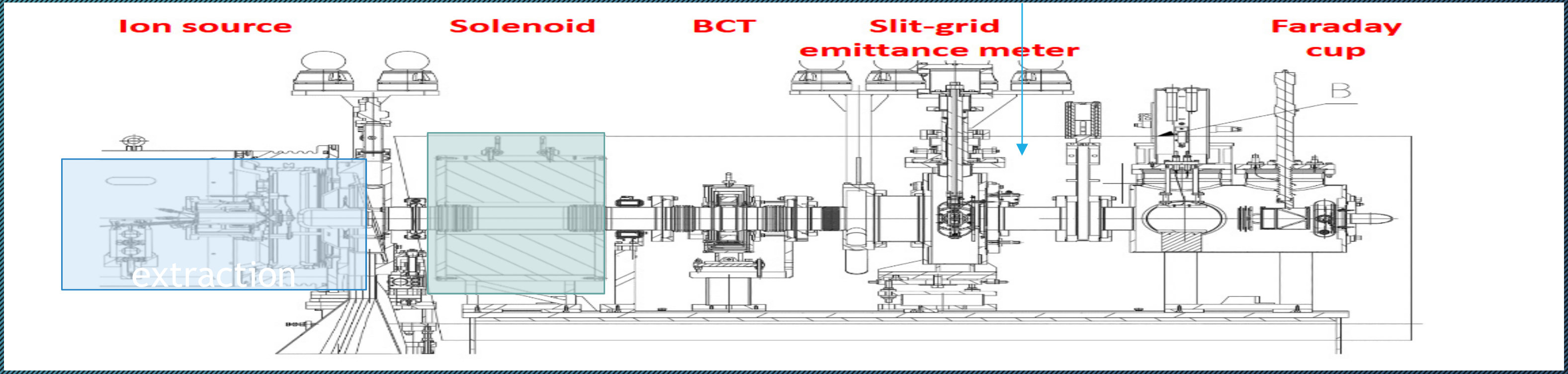
관심을 가져 주셔서 감사합니다.

Reserve

Source studies at the Linac4 test stand



LINAC4 source test stand

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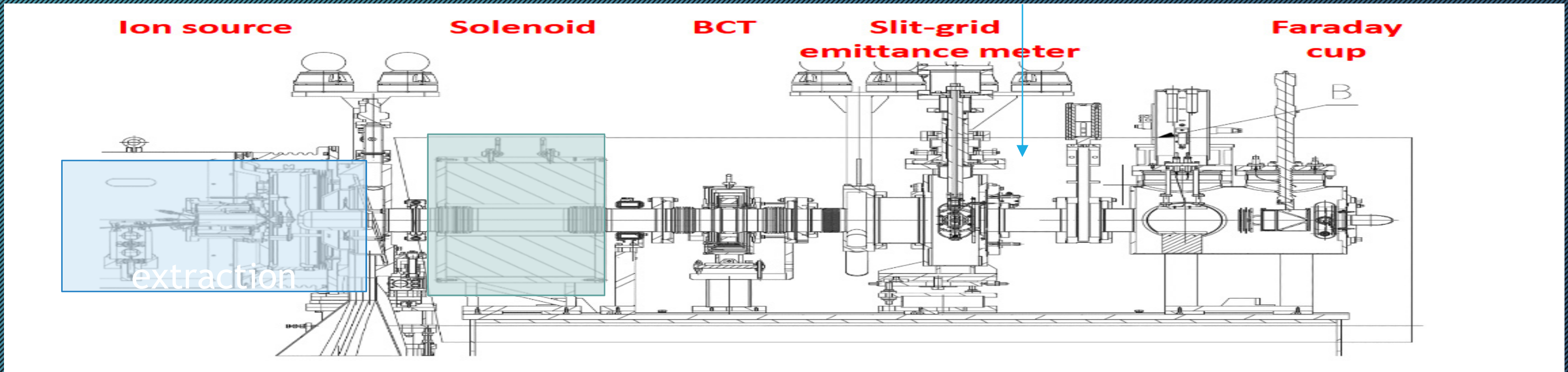
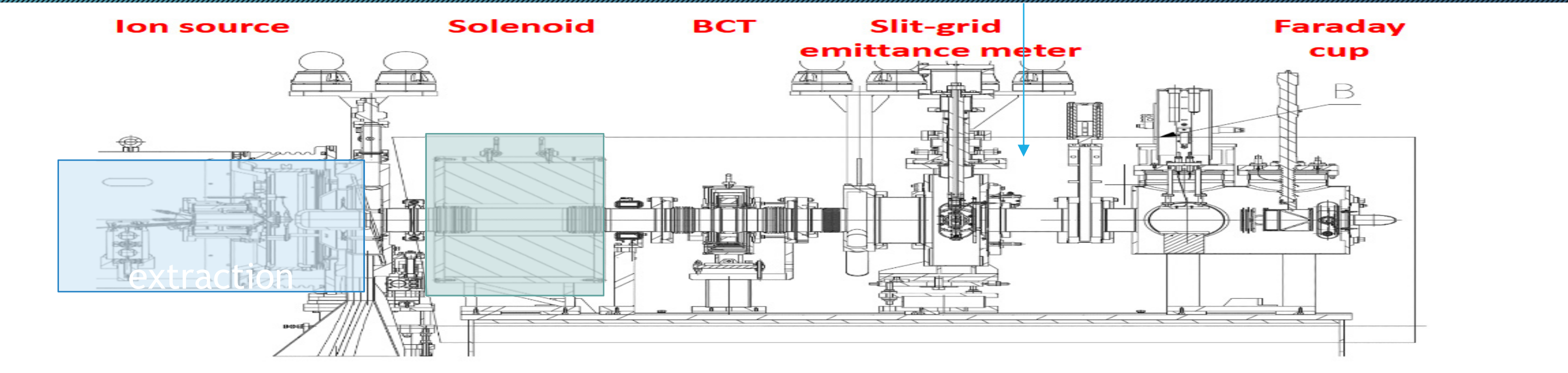


LINAC4 source test stand

Thorough campaign of current/emittance measurements in wide parameter scans.
Characterization of beam current and emittance for various controllable parameters.
Ongoing plasma modelling and beam dynamics studies for optimization of extraction. Quality factor to optimize is the <u>beam current in RFQ acceptance</u>.

Source studies at the Linac4 test stand



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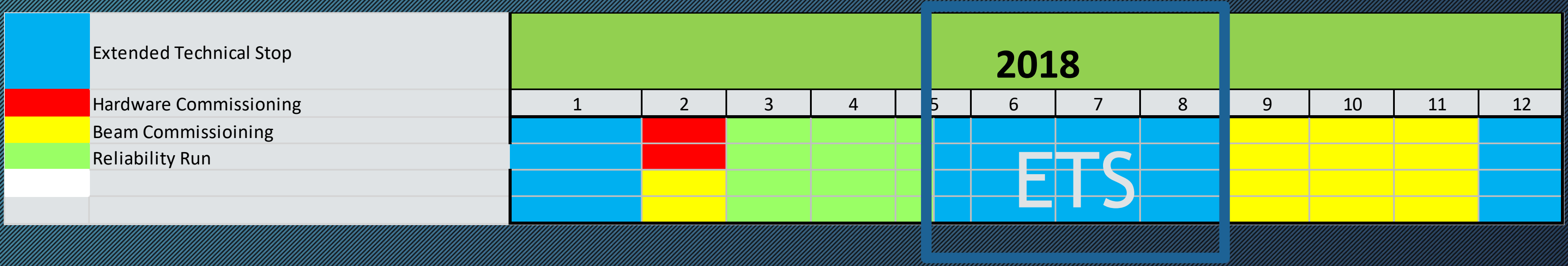
Milestones :

- validate the tracking codes in the extraction area
- understand if the emittance can be controlled and how

2018 milestones: 2) extended technical stop

- RF activities:
  - RF pick-ups exchange (all parts already at CERN), all Linac4 vented
  - In parallel, exchange of DTL tank1 RF coupler and tuning of tank 2 and 3 couplers, followed by re-calibration of all structures
  - Update of LLRF HW (cavity loops cards)

- Study solution to improve radiation-hardness of arc-detector klystron electronics (to be implemented during LS2)



2018 milestones : 3) re-commissioning

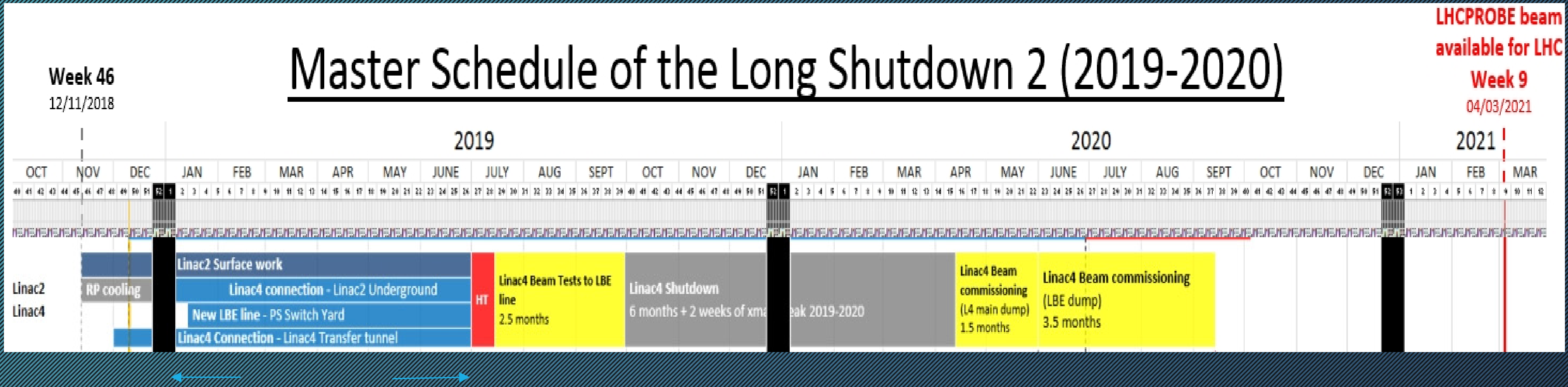
- RF activities:
  - RF pick-ups exchange (all parts already at CERN), all Linac4 vented.
  - In parallel, exchange of DTL tank1 RF coupler and tuning of tank 2 and 3 couplers. Followed by re-calibration of all structures.
  - Update of LLRF HW (cavity loops cards)

- Study solution to improve radiation-hardness of arc-detector klystron electronics (to be implemented during LS2).

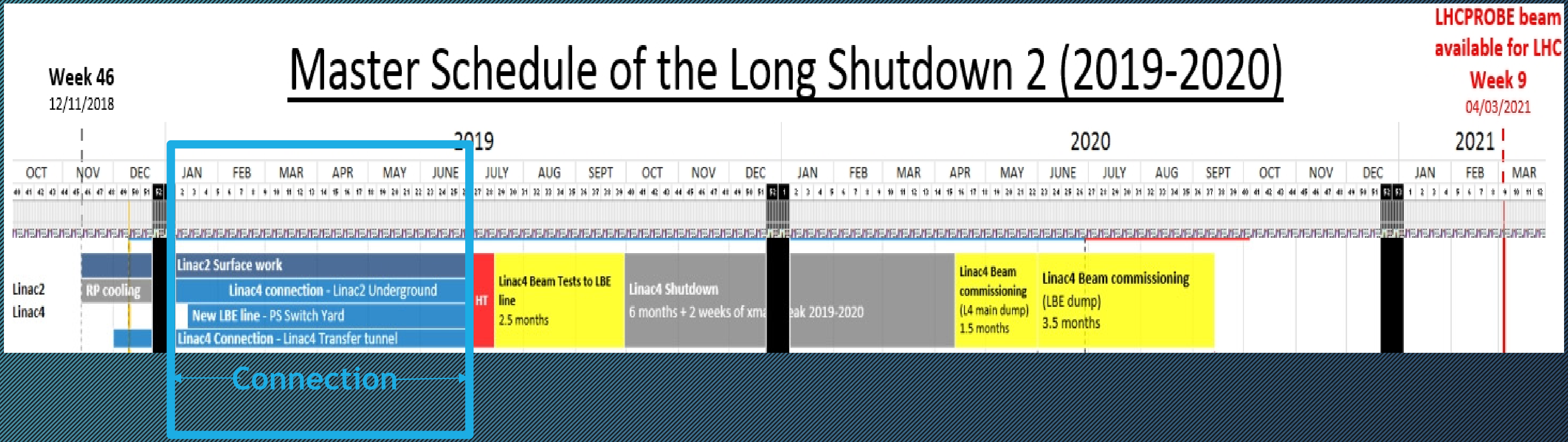
- 3 months commissioning period scheduled at the end of 2018 to validate all changes

	2018											
Extended Technical Stop												
Hardware Commissioning	1	2	3	4	5	6	7	8	9	10	11	12
Beam Commissioining												
Reliability Run									Beam tests			

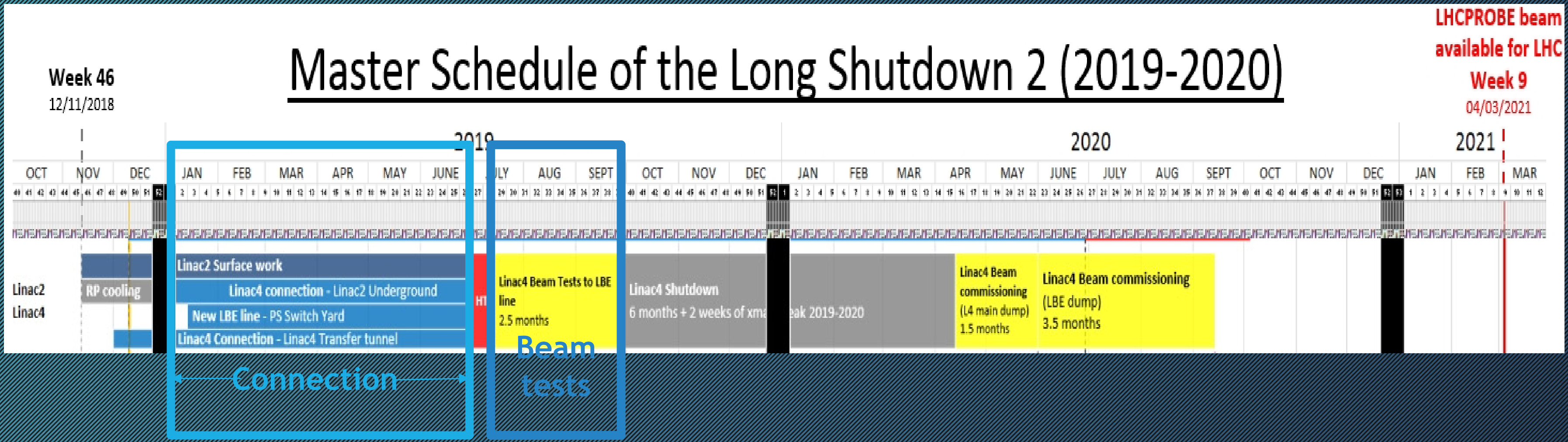
A look further: 2019-2020 milestones (LS2)



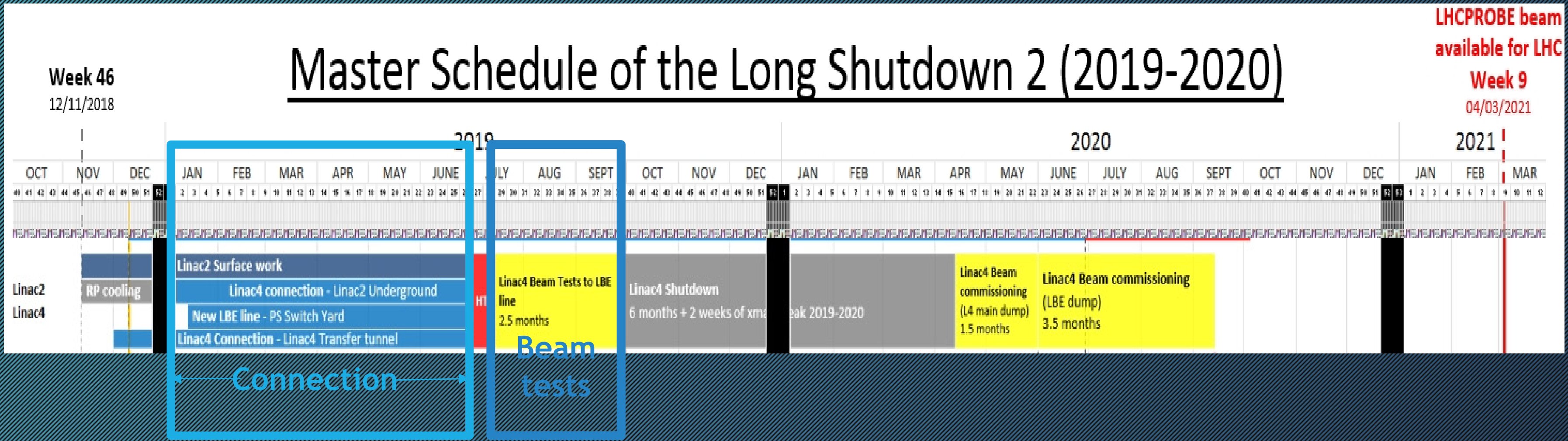
A look further: 2019-2020 milestones (LS2)



A look further: 2019-2020 milestones (LS2)



A look further: 2019-2020 milestones (LS2)



- LBE (transverse emittance measurement line at the end of Linac4) recommissioning:
  - 3 months of beam commissioning time have been requested to validate installation. Impact on LS2 but *critical time* to test machine performance and final beam quality at delivery point to the PSB.
- Decision about spare RFQ installation
- Development final source @ test stand and validation of changes

RF setup

Via beam-loading measurements:

Initial setup.
New pyjapc script developed for automatic phase scan of the cavities and beam loading measurements (thanks Daniel!)
Offline analysis still needed to fit the data, but procedure is now considerably faster.

Via energy measurements (TOF technique):

Fine tuning of the setting points.
TOF application validated , but still rather lengthy manual procedure: a dose of human discernment is still needed to interpret the data + offline analysis / fits.