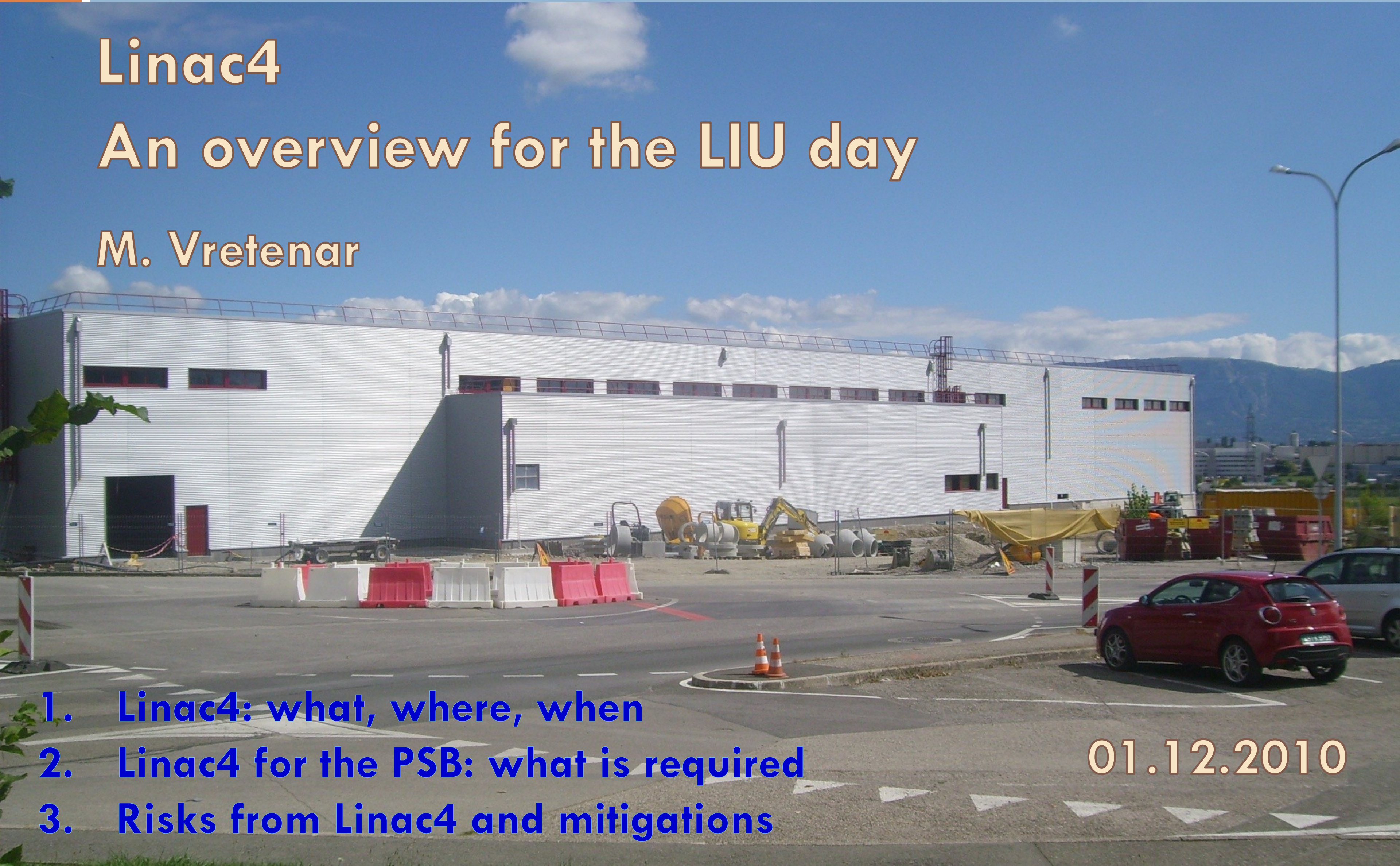
Linac4
An overview for the LIU day

M. Vretenar



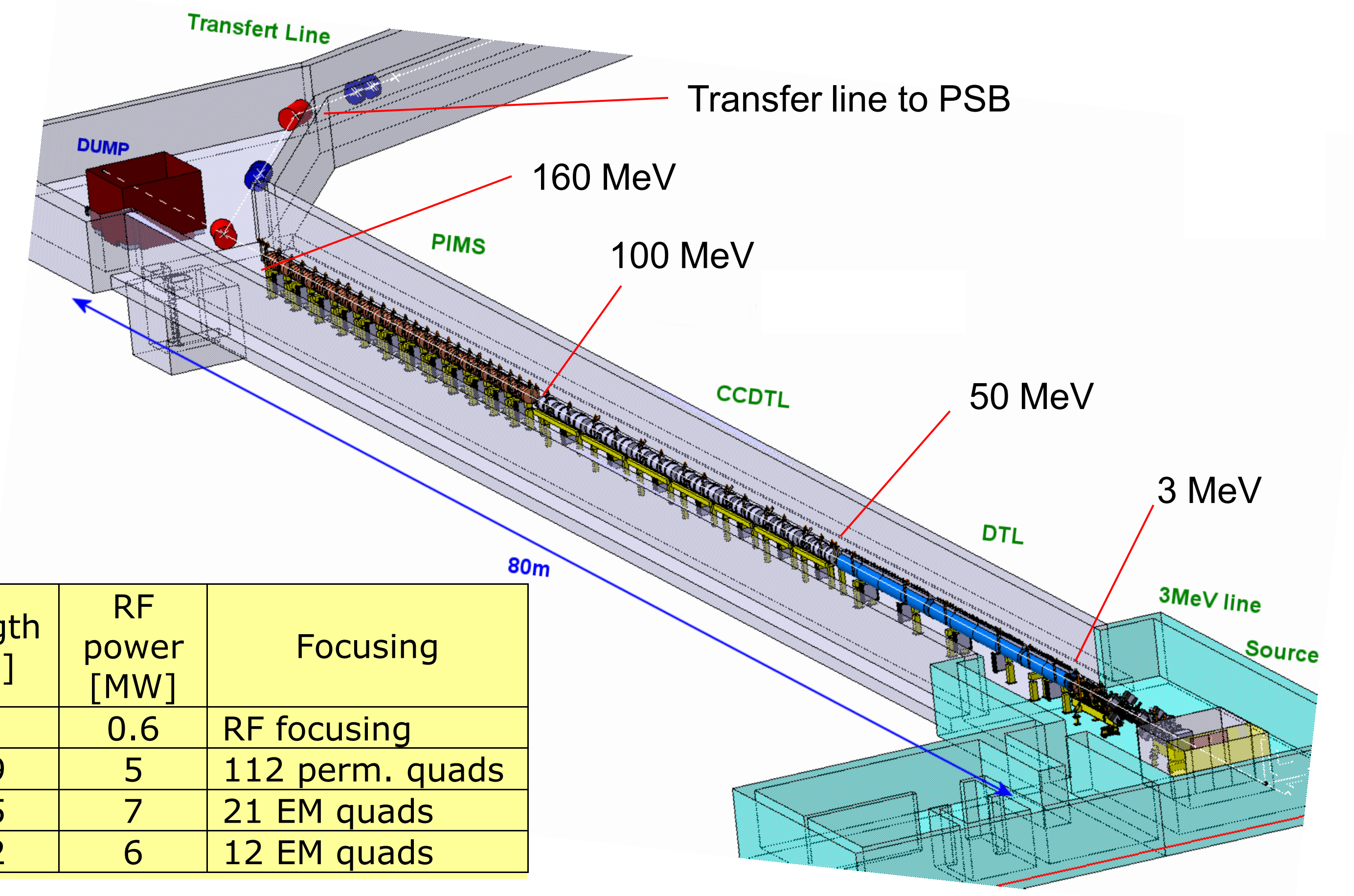
1. Linac4: what, where, when
2. Linac4 for the PSB: what is required
3. Risks from Linac4 and mitigations

01.12.2010

What we are building

- Linac4 is a normal-conducting H- linear accelerator for an energy of 160 MeV, made of:

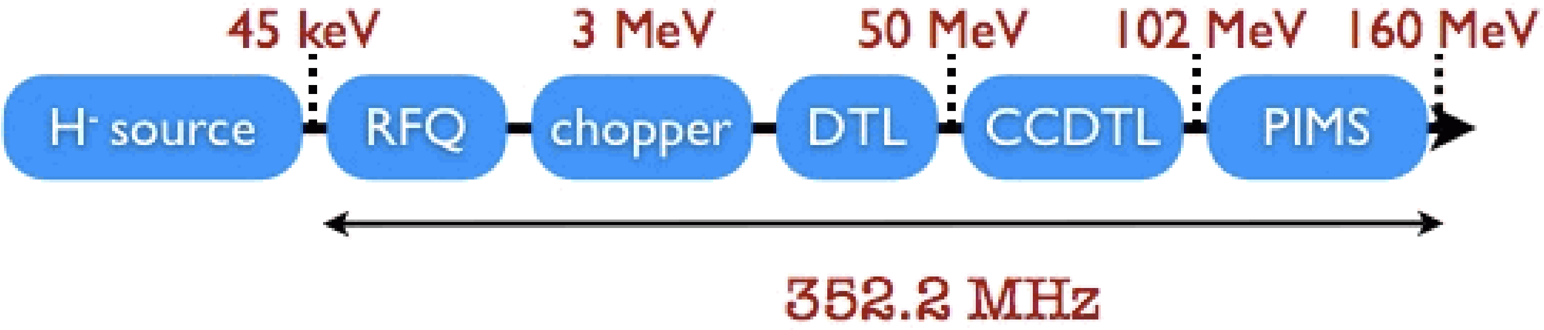
1. Pre-injector (source, magnetic LEBT, 3 MeV RFQ, chopper line)
2. Three types of accelerating structures, all at 352 MHz.
3. A 70 m transfer line towards the PS Booster (plus a dump line at linac end).



Linac length ~ 80 m

	Energy [MeV]	Length [m]	RF power [MW]	Focusing
RFQ	0.045 – 3	3	0.6	RF focusing
DTL	3 – 50	19	5	112 perm. quads
CCDTL	50 – 102	25	7	21 EM quads
PIMS	102 – 160	22	6	12 EM quads

Linac4 architecture

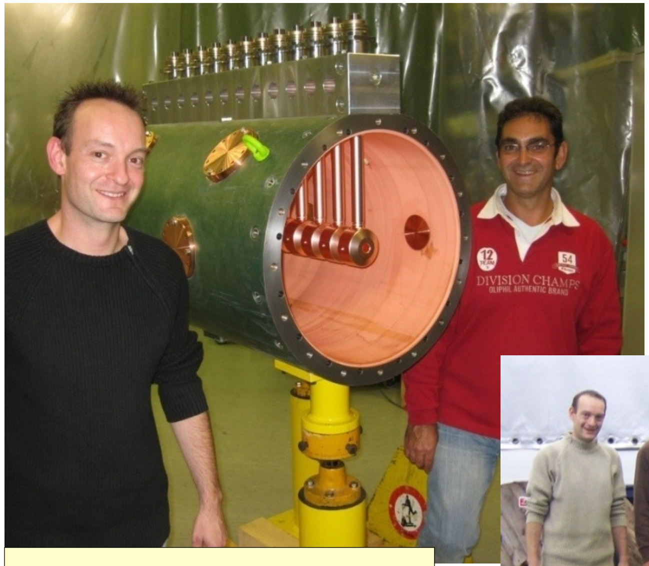


- No superconductivity (not economically justified in this range of beta's and for our low duty cycle)
- Single RF frequency of 352 MHz (no sections at 704 MHz, standardised RF allows for considerable cost savings)
- H- for injection in the PS Booster, chopping to minimize capture loss.
- High efficiency, high reliability, flexible operation → three types of accelerating structures.

Linac4 – Accelerating structures

Three structures of new design:

- DTL (Drift Tube Linac): complete revision of mechanical design w.r.t. other projects.
- CCDTL (Cell-Coupled DTL): new structure, first time used in an accelerator.
- PIMS (Pi-Mode Structure): new structure, first time used in a proton machine.


DTL prototype, 2009


CCDTL prototype, 2008


PIMS prototype, 2010

- R&D since 2003.
- Prototypes built (and tested at high RF power) for the three structures.
- Construction starting in 2010.

Linac4 – motivations, parameters

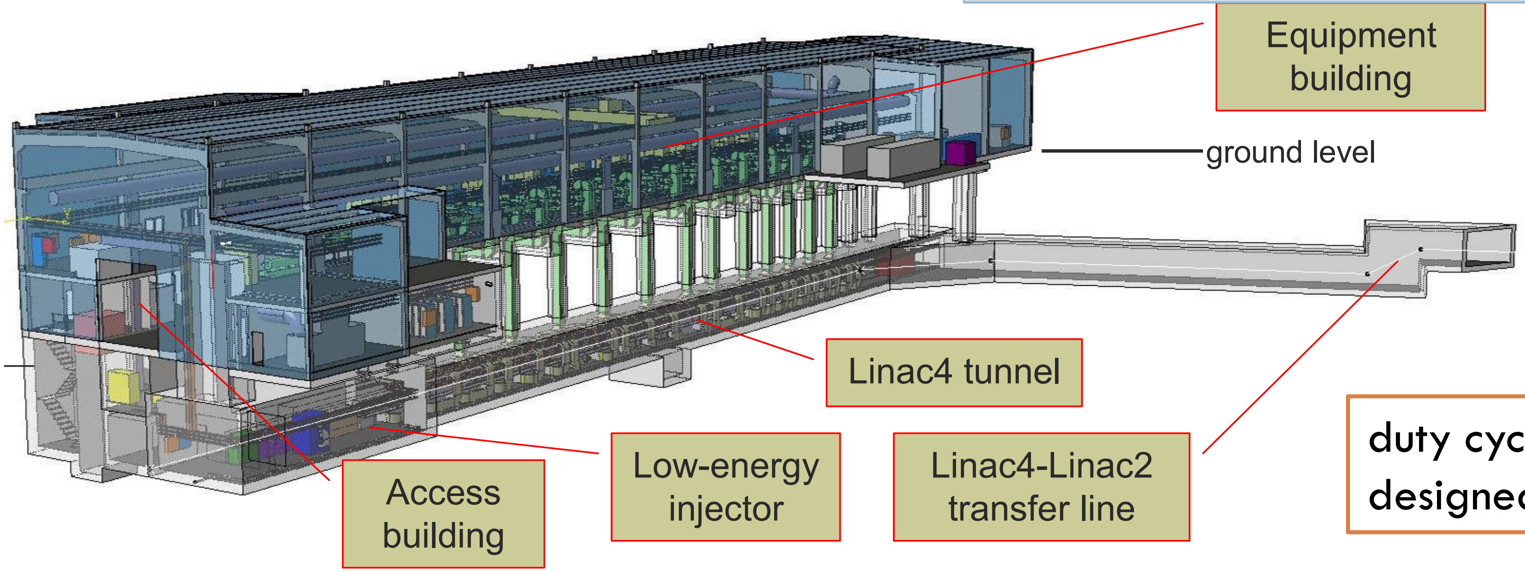
1. Higher intensity in PSB for the LHC upgrade.
2. Consolidation: improve long-term reliability and sustainability with regard to Linac2 (vacuum, RF).
3. Improved operational flexibility and reduced loss with chopping + H- injection).
4. Higher intensity for non-LHC users.
5. Prepare for a possible high-intensity upgrade (neutrino facility).

☞ Energy 160 MeV → factor 2 in $\beta\gamma^2$ from Linac2 → x2 intensity in PSB with same tune shift ($\Delta Q \sim N/\beta\gamma^2$).

☞ Use LEP RF frequency of 352 MHz → recuperate some klystrons and RF equipment.

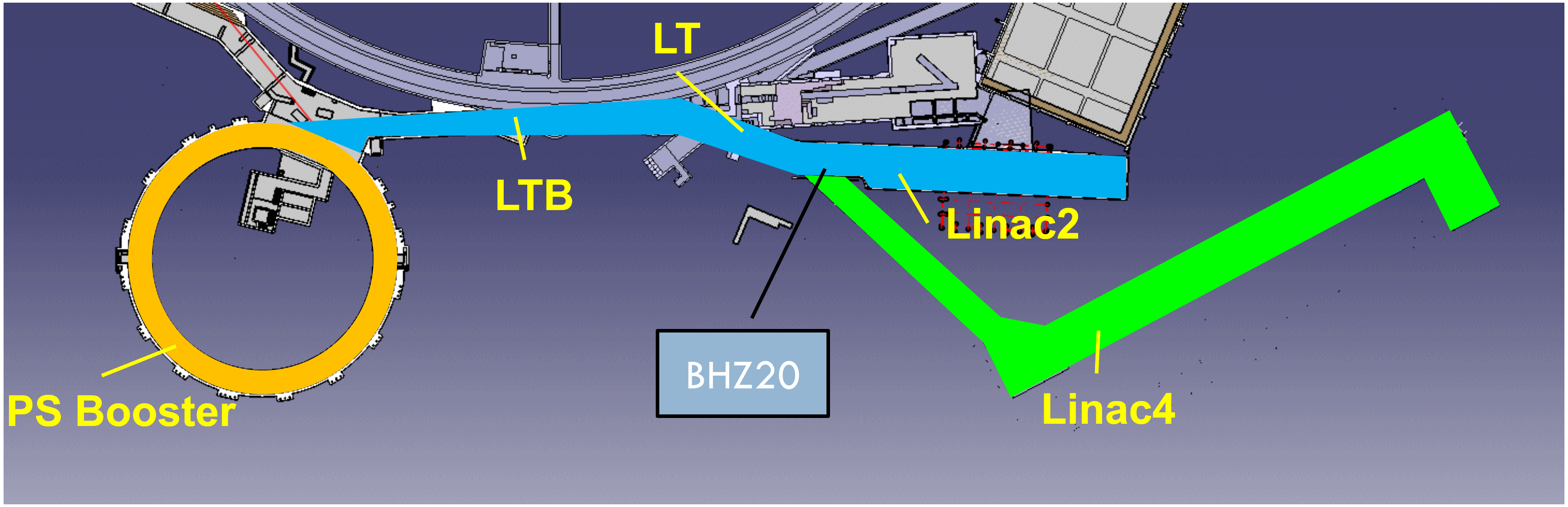
☞ Repetition frequency 1.1 Hz (900ms) - 2Hz max., upgradable to 50 Hz with new power supplies and additional cooling.

☞ Beam current 40 mA in 400 μs: >2 present PSB maximum.



duty cycle 0.8×10^{-3}
designed for 10%

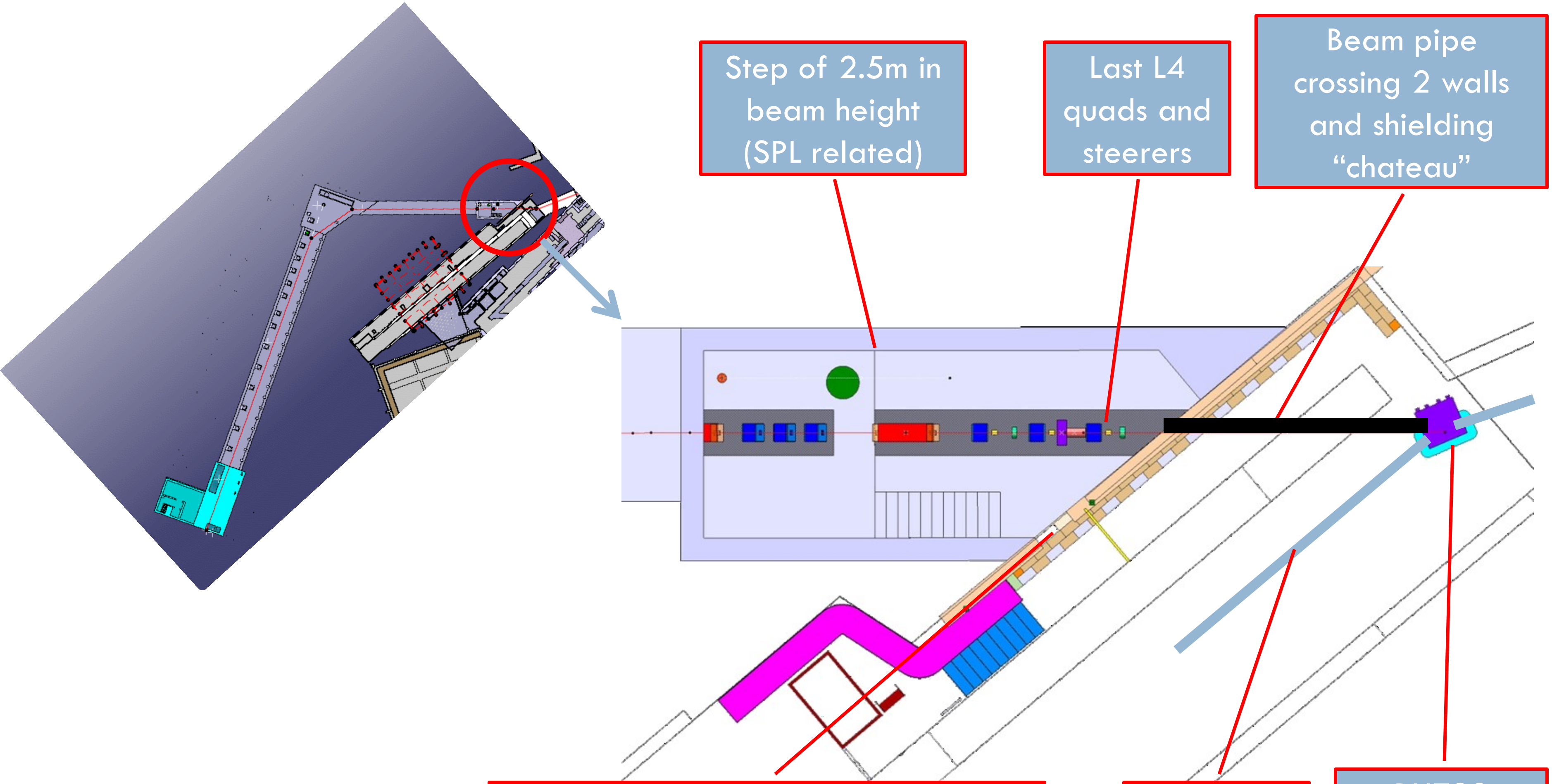
What is included in the project



Connection to the present beam lines takes place at the magnet LT.BHZ20. Beyond this magnet, the Linac4 project includes:

1. The modifications to the LT-LTB lines required to operate with Linac4 (in particular new measurement lines LBE-LBS at PSB entrance).
2. The modification to the PSB injection region required for H- and higher energy.
3. The studies and commissioning preparation required for higher intensity in PSB.

The connection point



Step of 2.5m in beam height (SPL related)

Last L4 quads and steerers

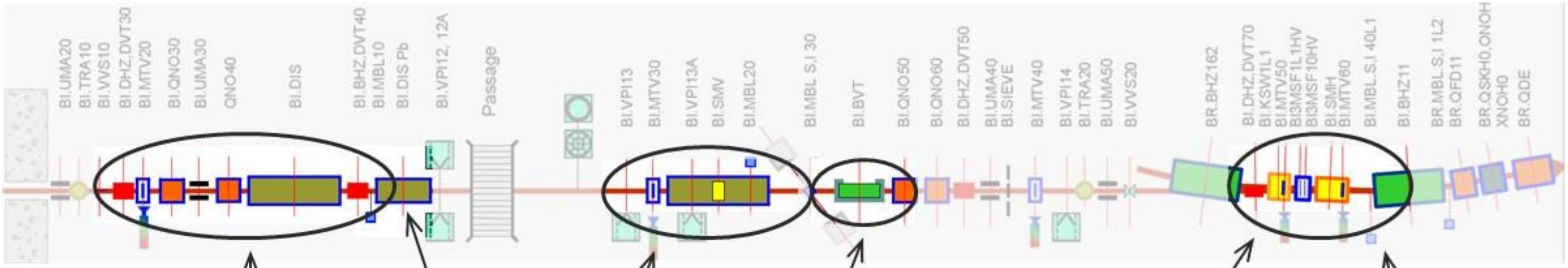
Beam pipe crossing 2 walls and shielding “chateau”

Door connecting Linac4 to Linac2 zones (L4 emergency exit, inside radiation controlled area)

LT line (Linac2 to PSB)

BHZ20 (connecting magnet)

PSB injection and beam optics



Remove obsolete BI.DIS Pb

Modify BI.DIS for 4.3 mrad @ 160 MeV

Performance increase of 1.9 in ∫B•dl of BI.DVT30, BI.QNO30, BI.QNO40, BI.DVT40.

~0.36 Tm required from BI.BVT for ~175 mrad @ 160 MeV

New BI.SMV, 4 mm thick septum and 70 mm horizontal aperture for ~165 mrad @ 160 MeV with associated new pulse generator.

Relocate modified KSW1L1 magnet to PSB period 16, build new pulse generator.

Rebuild the 2.654 m injection region of each of the 4 PSB rings:
- 4 new BS magnets,
- Foil holder and handler,
- Dump for unstripped H^0/H^-,
- Beam Instrumentation.

Slide courtesy of W. Weterings

Linac4 – The challenges

- **Low-energy section: ion source, RFQ, chopping**

  generation of low-emittance intense H- beams, transport and emittance preservation through LEBT and RFQ, efficient transport and chopping

- **Accelerating structures**

  design prototyping and construction of high efficiency RF structures

- **Linac beam dynamics**

  emittance preservation, low loss design in case of high-duty operation

- **PSB injection and beam optics**
- **Reliability**

  benchmark: present availability of Linac2 is 98.5%!

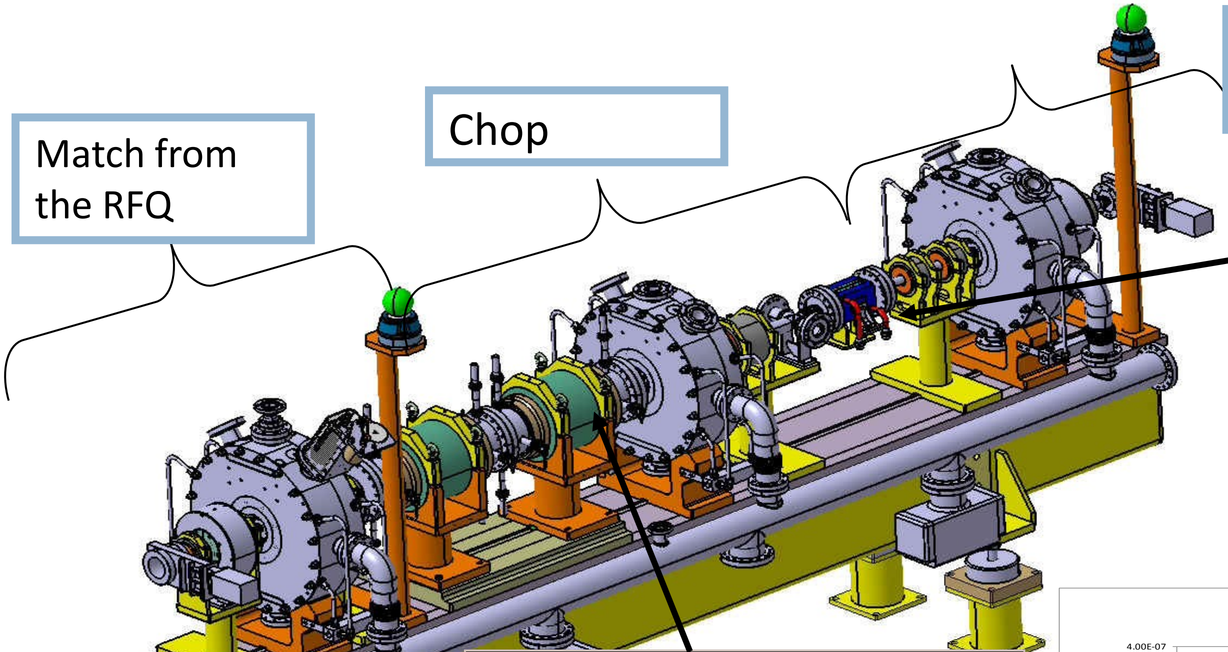
Linac4 Beam Parameters

Ion species	H^-	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Frequency	2	Hz
Max. Beam Pulse Length	0.4	ms
Max. Beam Duty Cycle	0.08	%
Chopper Beam-on Factor	65	%
Chopping scheme:	222 transmitted /133 empty buckets	
Source current	80	mA
RFQ output current	70	mA
Linac pulse current	40	mA
Transverse emittance	0.4	π mm mrad

Max. repetition frequency for accelerating structures 50 Hz

“chopping”

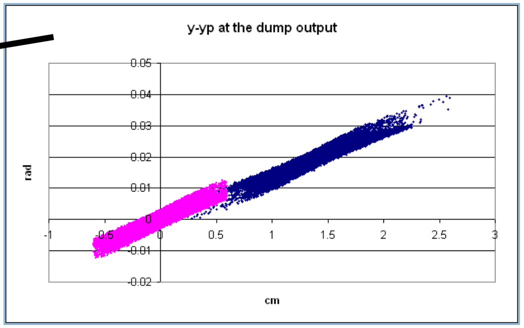
removing microbunches (150/352) to adapt the 352MHz linac bunches to the 1 MHz booster frequency

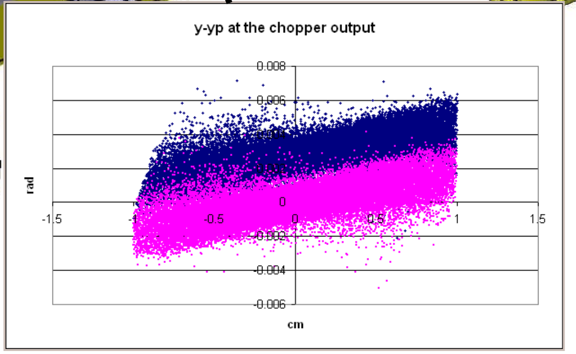


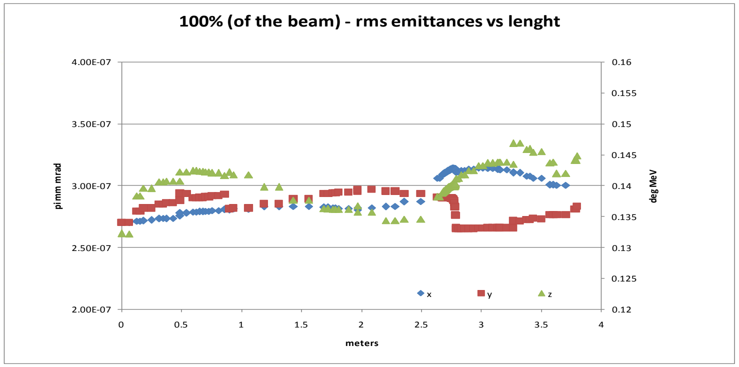
Match from the RFQ

Chop

Match to the DTL





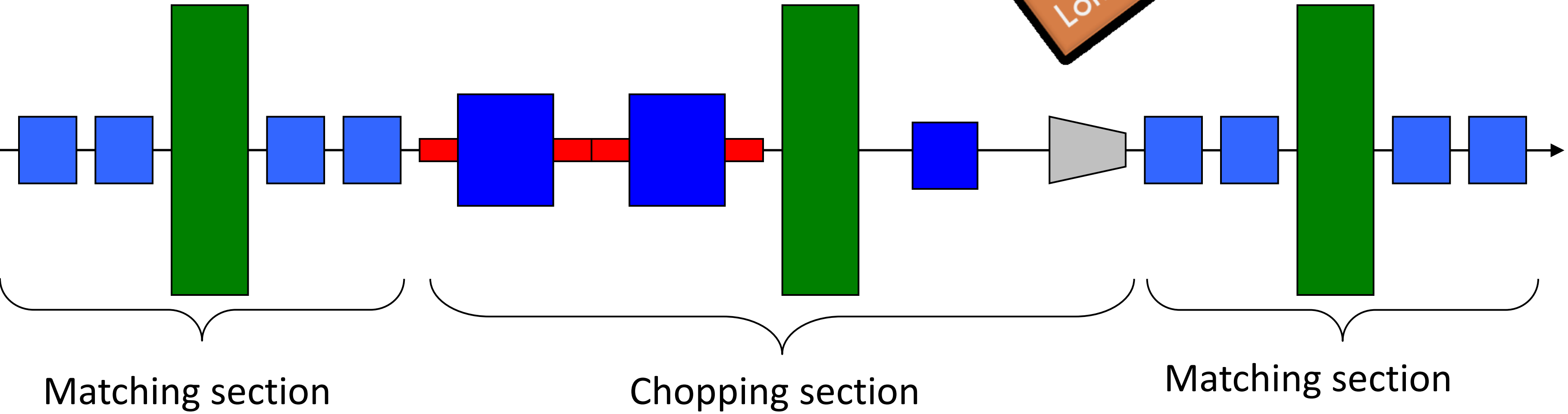


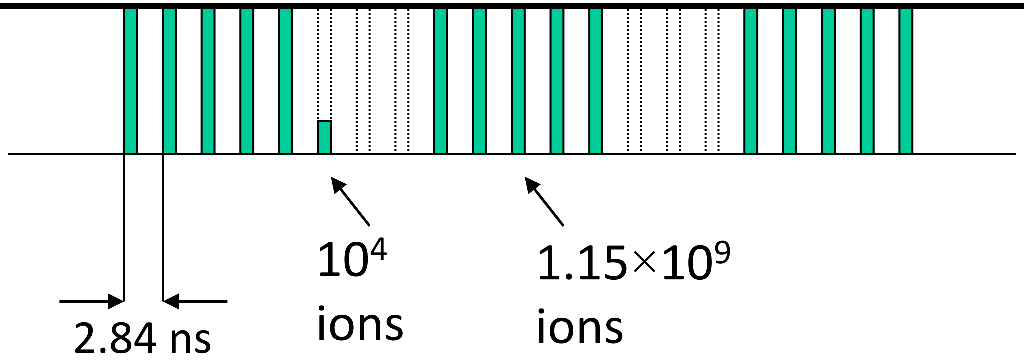
Emittance increase 20-30%

Slide courtesy of A. Lombardi

Chopper line layou

Slide courtesy of A. Lombardi

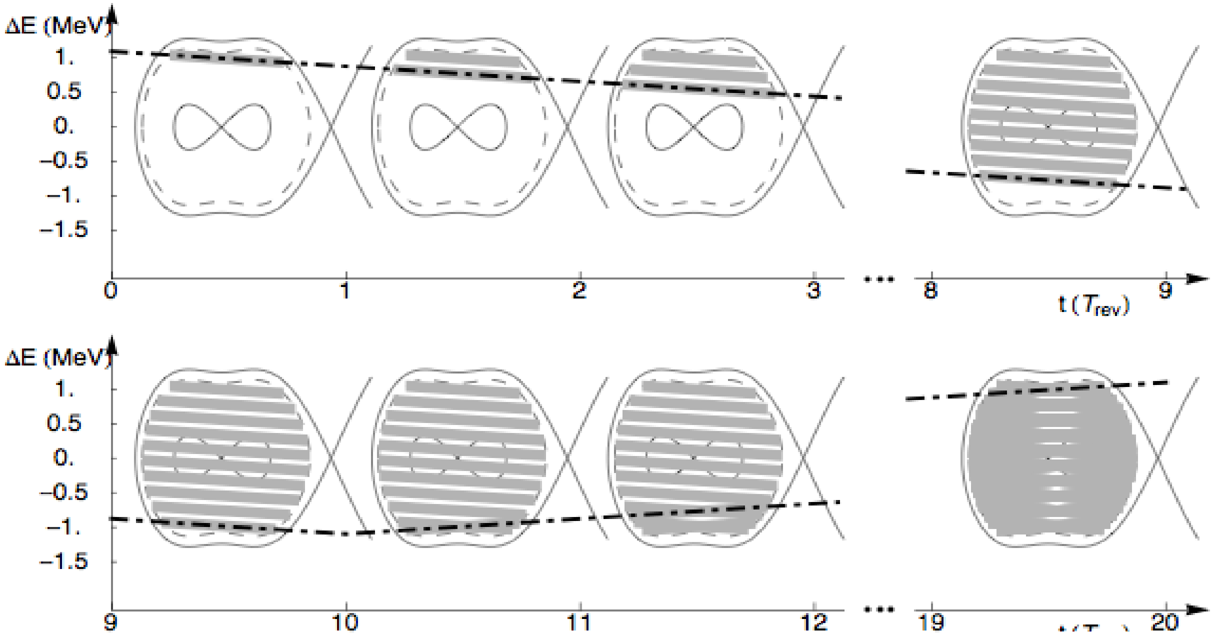




for PSB : suppress 150/352 microbunches (1MHz)
for SPL and Nufact : suppress 3/8 microbunches (40 MHz CERN nufact)

Pulse structure - High brightness & intensity beams (LHC, ISOLDE, CNGS?)

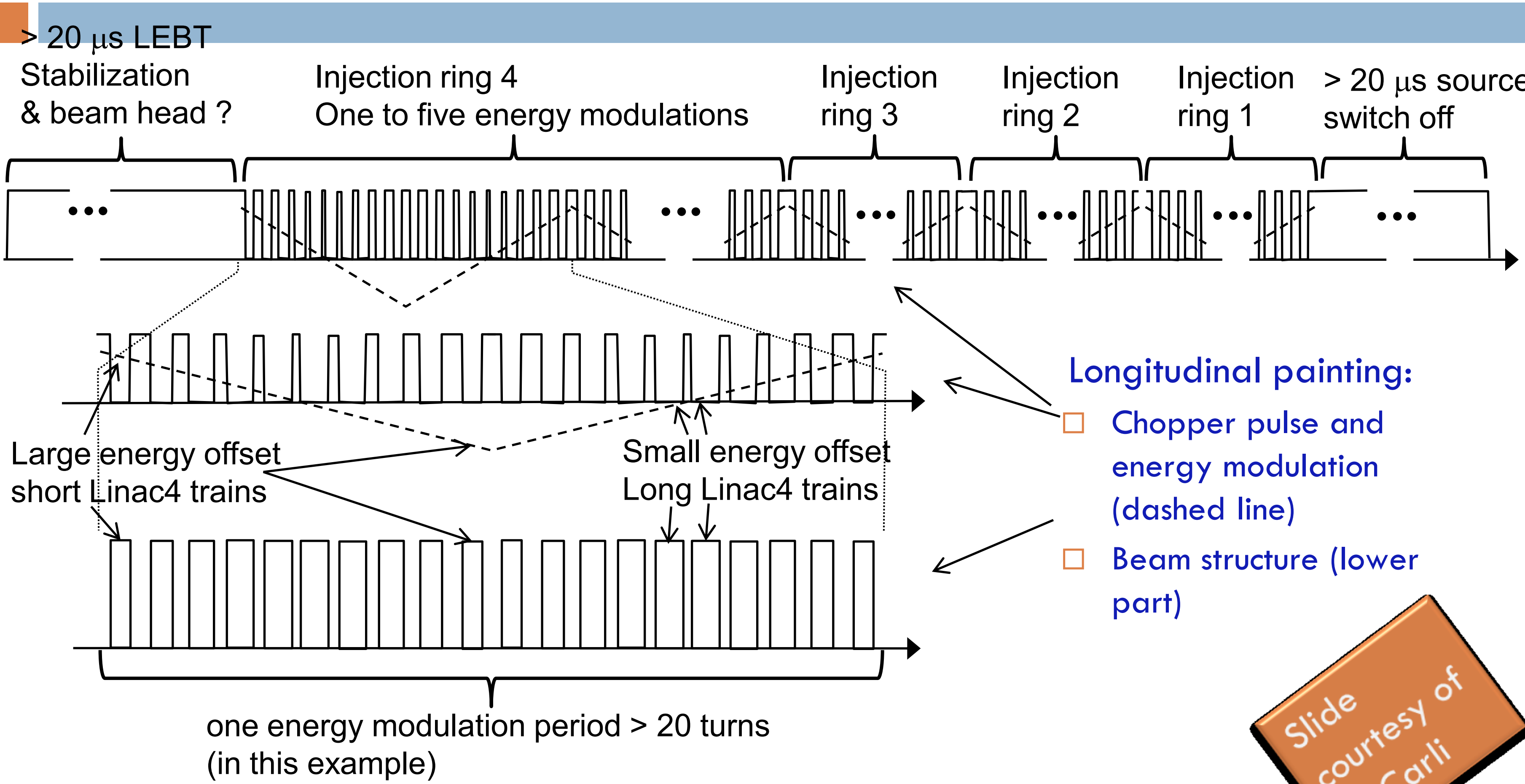
Injection on ramp into waiting buckets



- Aim: Optimize bunching factor for highest beam brightness/intensity
- Principle:
  - Saw-tooth energy modulation of Linac4 beam
  - Linac4 chopper letting only bunches, ending inside waiting PSB bucket, through
- Baseline (2007) under discussion:
  - Energy modulation period > 20µs, amplitude ±1.2 MeV and momentanous spread σ_E=0.1
  - Already too high intensity for LHC with nominal 65mA peak current
  - Under discussion: minimum energy modulation period - how to use that in the Booster

Slide courtesy of C. Carli

Linac pulse structure High brightness & intensity beams (LHC, ISOLDE, CNGS?)



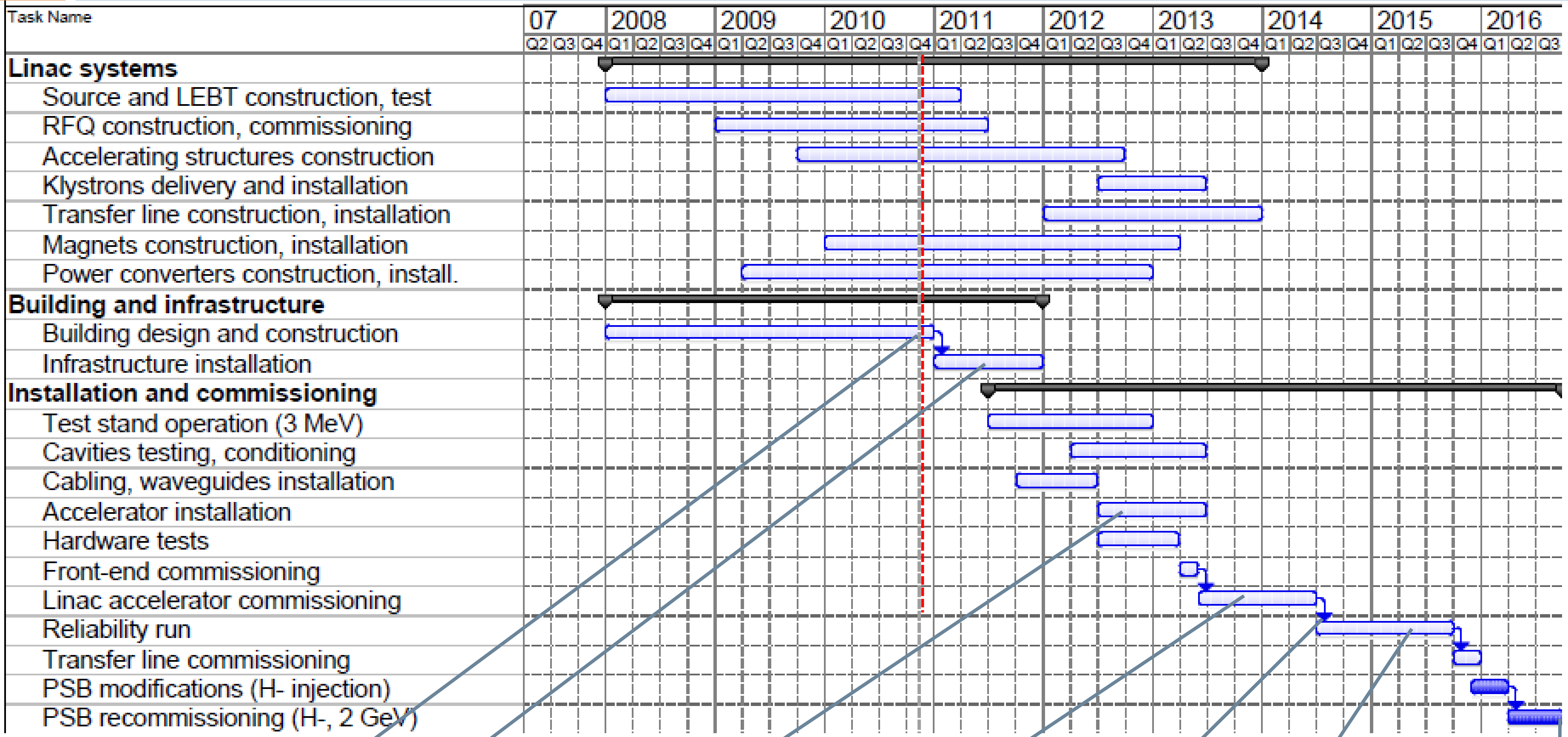
Longitudinal painting:

- ☐ Chopper pulse and energy modulation (dashed line)
- ☐ Beam structure (lower part)

Slide courtesy of C. Carli

- ☐ For illustration energy modulation within 20 turns
- ☐ Injection on ramp -> differences of field of the four rings at time of filling compensated by “BdI”s

Linac4 – schedule



Building delivery

2011: Infrastructure installation

2012/13: Accelerator installation

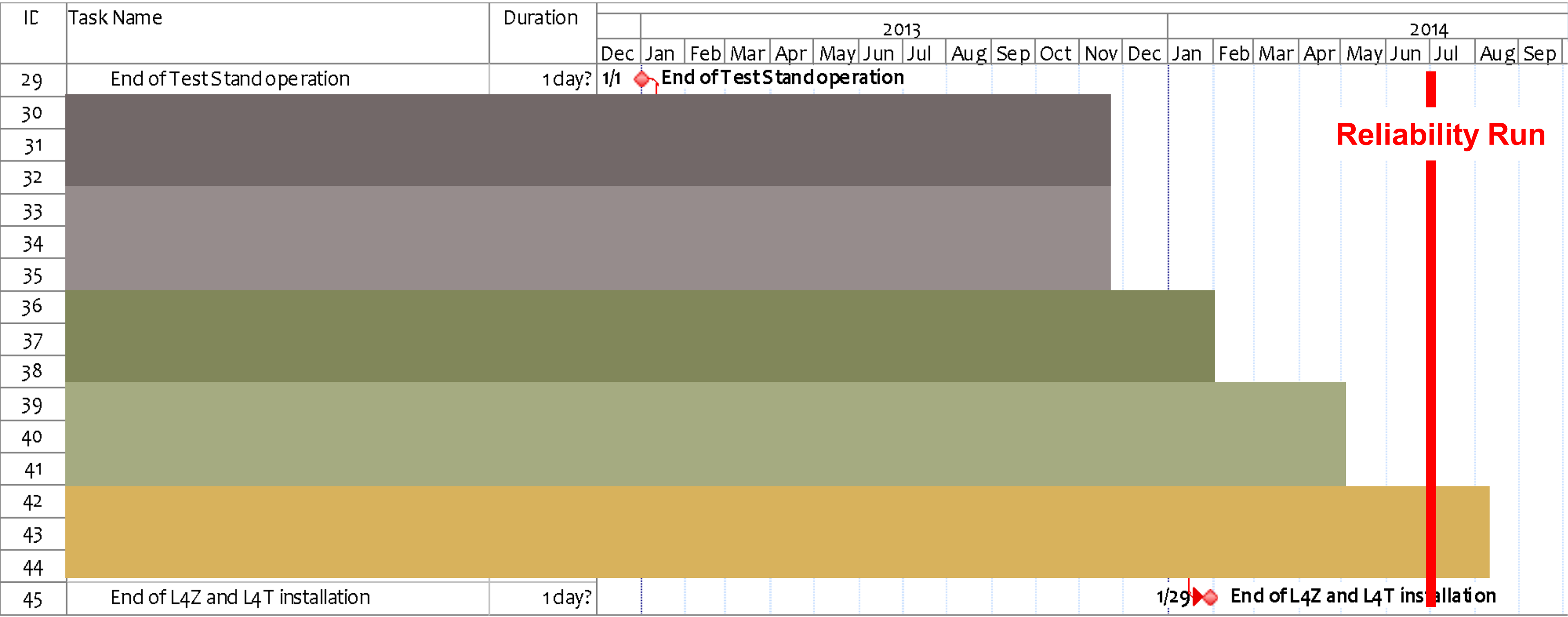
2013/14: Commissioning

July 2014: Linac4 ready

2014/15: Reliability run

2016: foreseen shutdown for connection to PSB

Commissioning



- ☐ ▨ With the diagnostic line Low Energy

  ▨ After the Chopper line and after the DTL tank1

- ☐ 🟩 With the diagnostic line Medium Energy

  🟩 After the 3 DTL and after the 7 CCDTL

- ☐ 🟨 Last structures installation

- ➢ Commissioning of the linac4-main dump line = February 2014

+ hardware test of the new transfer line

Schedule PSB connection and after

COMPOSITION LINAC4 SHUT-DOWN	1	2	3	4	5	6	7	8	month
Cool-down radiation in PSB area	🟨								
Connection transfer line (+beam tests?)	🟨								
Modification PSB hardware		🟨	🟨	🟨					
Commissioning PSB with new hardware					🟨	🟨	🟨		
Start-up PS-SPS								🟨	

Original schedule (8 months overall LHC shut-down) – now needs to be coordinated (extended?) with PSB upgrade.

Note that the scope of the project is:

- at PSB start-up, reproduce the same beams as with Linac2.
- after about 1-2 years of MDs and improvements, provide higher intensity (to LHC first and then to other users).

From the Linac4 Project Plan approved by R. Aymar in June 2007:
“the PSB will deliver beam for physics using the new injector at start-up 2012, reaching its maximum performance after a few years of operation“.

How sensitive are we to variations of the nominal Linac4 beam parameters?

Performance with Linac4

1. LHC: Revised version of the Chamonix 2010 table (25 ns b.s.).
Max. PSB intensity 4x3.6x10^{12} ppp = 1.44x10^{13}

LHC INJECTORS WITH LINAC4		Nominal LHC Single batch	Maximum Single batch	Maximum Double batch	PSB @ 2 GeV Double batch
PSB out	ppr	3.25 x10^{12} *(2bunch/ring)*	3.6 x10^{12} *(2bunch/ring)*	2.05 x10^{12} *(1bunch/ring)*	*3.2 x10^{12} (1bunch/ring)*
($\varepsilon^* \leq 2.5\ \mu m$)		↓ *(6 bunches, h=7)*	↓ *(6 bunches, h=7)*	↓ *(6 bunches, h=7)*	↓ *(6 bunches, h=7)*
PS out, per pulse	ppp	9.72 x10^{12}	*10.8 x10^{12}*	*12.3 x10^{12} (scaled 1998 limit, 206ns bunches)*	*19.2 x10^{12} (PS limit scaled to 2 GeV)*
PS out, per bunch	ppb	1.35 x10^{11} *(72 bunches)*	*1.5 x10^{11} (72 bunches)*	*1.7 x10^{11} (72 bunches)*	*2.7 x10^{11} (72 bunches)*
($\varepsilon^* \leq 3\ \mu m$)		↓ *15% loss*	↓ *<15% loss*	↓ *20% loss*	↓ *20% loss*
SPS out	ppb	1.15 x10^{11}	*>1.3 x10^{11}*	*1.37 x10^{11}*	*2.1 x10^{11}*
Goal:		Nominal intensity in single batch: shorter filling time, lower losses and emittance growth.		Potential for ultimate intensity out of PS in double batch.	Potential for > ultimate with hardware modifications, as PSB @ 2 GeV.

2. ISOLDE: Goal is twice present intensity in PSB = 2x3.5x10^{13} ppp = 7.0x10^{13}

Expected beam loss in PSB

LHC beams	Present	Expected with Linac4	Comments
Injection	50%	~5%	H-: no septum loss, but 2% unstripped
Capture	5%	~3%	High capture efficiency
Acceleration	5%	~5%	
Total	60%	~13%	

Present loss values courtesy of Klaus, for typical cases.

ISOLDE beam	Present	Expected with Linac4	Comments
Injection	29%	~5%	H-: no septum loss, but 2% unstripped
Capture	23%	~3%	reduced capture loss with chopper
Acceleration	6%	~6%	
Total	58%	~14%	

Note: activation (in Cu or SS) is about 8 times higher for a proton lost at 160 MeV than at 50 MeV → we have to reduce losses by a factor ~10 if we want to have comparable levels of activation in the PSB with Linac4 (achievable thanks to H- and chopper).

Requirements for Linac4 current

	PSB out (ppp)	PSB in (ppp)	Linac4 current in 400µs (mA)	Linac4 current in 160µs (mA)	Linac4 current in 80µs (mA)
LHC present	0.7×10^{13}	0.9×10^{13}	(3.6)	9	**18**
ISOLDE present	3.5×10^{13}	4.5×10^{13}	**18**	-	-
LHC max.	1.4×10^{13}	1.8×10^{13}	(7.2)	**18**	**36**
ISOLDE max.	7.0×10^{13}	9.0×10^{13}	**36**	-	-
		with 20% margin for beam loss		40 turns / PSB ring	20 turns / PSB ring

Linac4 design 400 µs pulse and 40 mA current correspond to 10^{14} ppp (twice present ISOLDE with some additional margin).

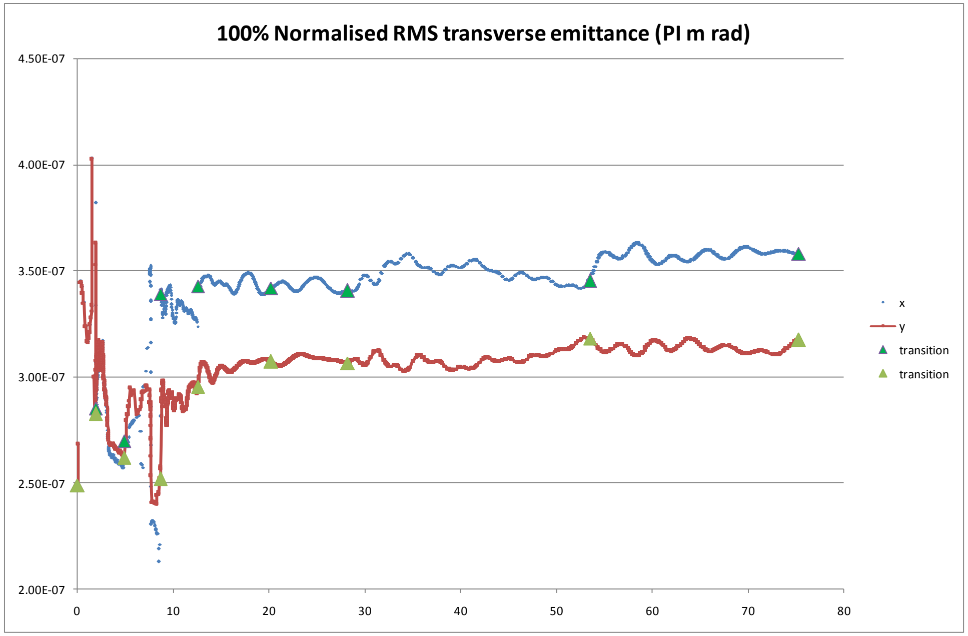
- A linac current of 20 mA allows to produce the present beams in the PSB + a full intensity LHC beam with 40 turns injection
- The design current of 40 mA is required for the ISOLDE beam and for a full intensity LHC beam with 20 turns injection

Requirements for Linac4 emittance

- Design transverse emittance from ion source 0.25 π mm mrad (rms)
- Design transverse emittance at PSB input 0.4 π mm mrad (rms)

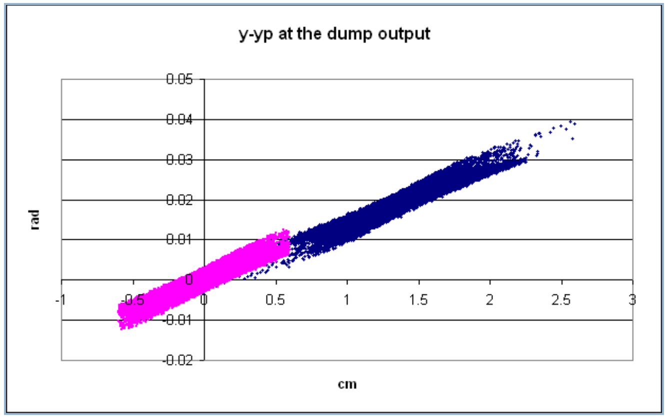
At a certain moment, we will probably have to compromise between current and emittance (our of the source).

What are our margins in terms of emittance?



Maximum acceptances (no errors, zero current)

RFQ : 0.55 π mm mrad
Chopper : 0.4 π mm mrad
DTL : 0.8 π mm mrad
(comparable for other accelerating structures, larger for the transfer line)
The PSB can accept a somehow larger emittance



Conclusion: we have a safety margin until reaching the RFQ acceptance limit
The limitation in the chopper line will lead to more particles in the “empty buckets”

Linac4 Risks and possible mitigations

Linac4 Risk Analysis – October 09

242 topics were discussed in detail during the workshops
(10 half-day workshops)

145 quantitatively assessable risks were identified & evaluated.

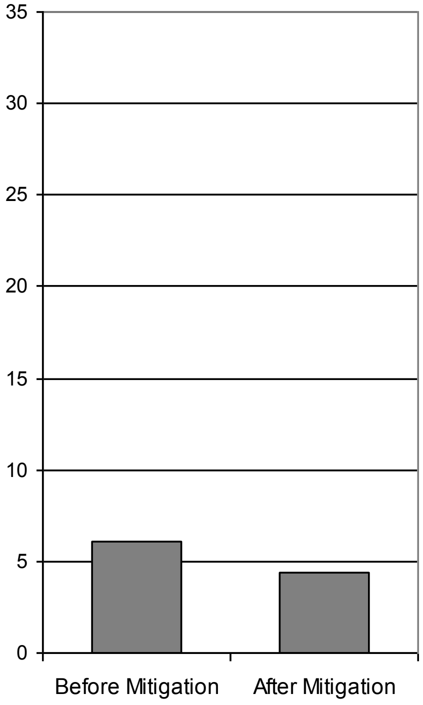
23 uncertainties were identified and evaluated.

115 mitigations and action items were identified.

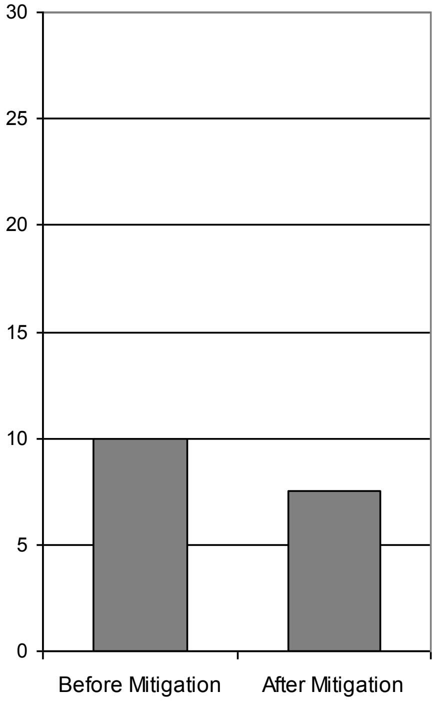
Risk Analysis results for Linac4

Summary – Monte-Carlo-Simulation Results

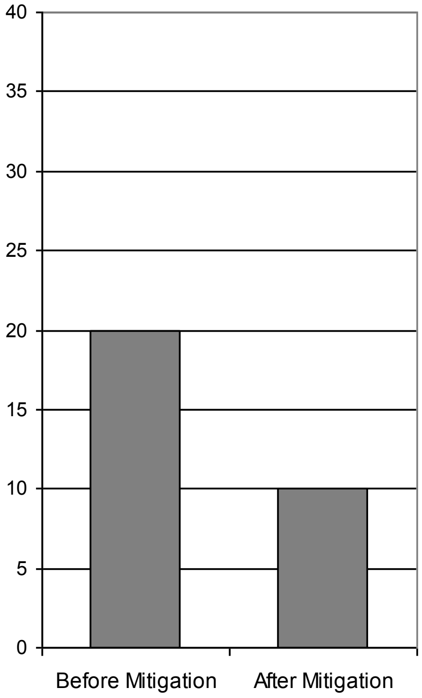
Cost
Increase [m CHF]



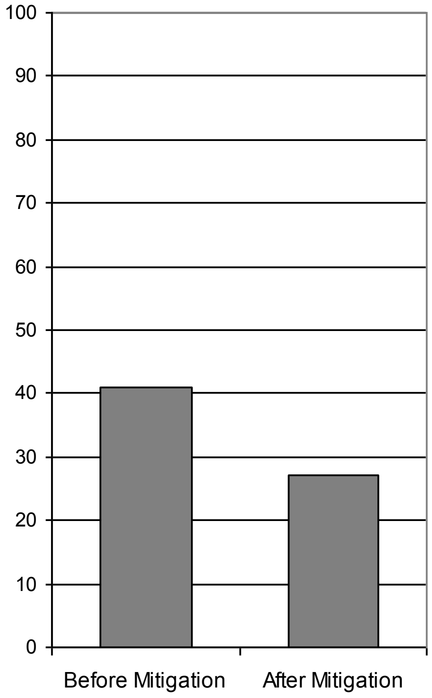
Time
Delay [month]



Scope
Reliability Red. [%]



Quality
Beam Brightness Red. [%]



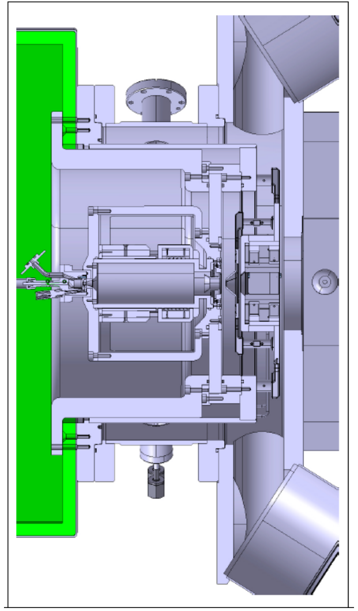
Overall Cost of Mitigation: 4.7 m CHF

Benchmarks could be established in case impact categories and thresholds are consistently defined across different CERN projects

Performance risk register - top

Risk - ID		Group	Risk Description	Cost Increase [CHF]	Time Delay [month]	Scope - Availability Reduction during 1st	Quality - Potential Ultimate Beam	Probability before Mitigation	Priority	Mitigation Description
207	LEP klystrons - Reduction in beam current	RFHP	Reuse and modification of some of the old klystron equipment is planned. The risk is lower performance / reduction in beam current.				20.0	50.0%	10.00	
061	3 MeV test stand - Quality of results / Calibration	BEAM	In case we cannot calibrate the line there will be a quality and performance risk for all subsequent topics.				30.0	25.0%	7.50	23.09.2009: Description of mitigation: * Push for timely construction of test stand * More time and additional manpower for measurement, despite of additional delay Costs: 1.5 FTE (but not for Linac4)
163	Diagnostics and control	COM	Diagnostics and control might not be ready or might not work correctly.		1.00		30.0	25.0%	7.50	24.09.2009: Description of mitigation: * Put more pressure on the instrumentation and contro groups.
054	Ion Source - Final design parameters / Goals	BEAM	Poor performance of the ion source -> LEBT. The risk is that we may fail to reach the final design parameters / goals (e.g. the required beam brightness).	10,000			25.0	25.0%	6.25	23.09.2009: Description of mitigation: * Alternative 1 - Change source type (--> 500k CHF), bu add. delays of 12 months * Alternative 2 - Add Cesium (--> Redesign 150k CHF), 3 months (but can be compensated) * Alternative 3 - Increase the pulse length. (--> 100k CHF; no time delay but impact on quality possible) Cost of mitigation: * Alternative 1 - 500k CHF * Alternative 2 - 150k CHF * Alternative 3 - 100k CHF

The H- source problem



RF Volume source of the DESY design, selected for the high reliability (external antenna) and for being Cesium-free.

Improved RF generator (100 kW) and matching network for higher current, extraction at 45 kV (at DESY 35 kV with 30 kW RF was giving 30 mA).

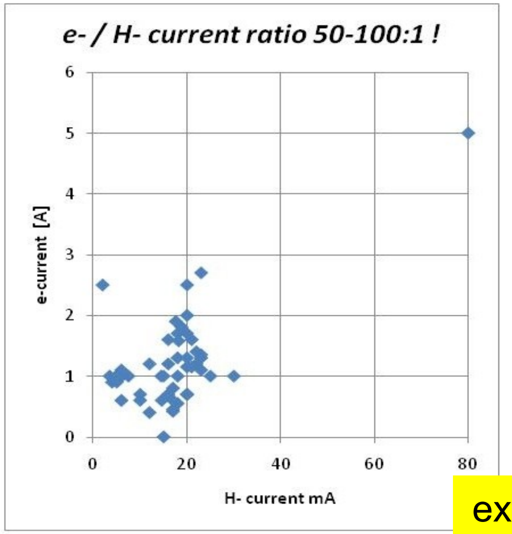
So far, could not operate at 45 kV (and 20-30 mA extracted at 35 kV).

Reason: intense electron production, which melts the e⁻ dump. Vaporization (and destruction) of the dump induces sparks preventing the source operation.

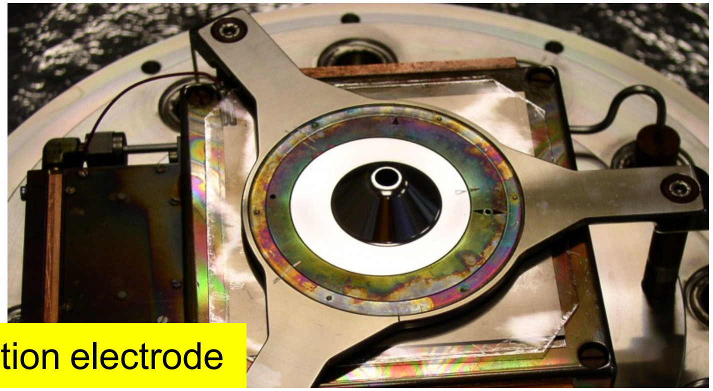
Strategy:

a. upgrade the present source (new tungsten dump).

b. Consider other source designs and options (cesium for surface production, etc.).



e- / H- current ratio 50-100:1 !



extraction electrode

Carbon dump after months of 35 keV operation

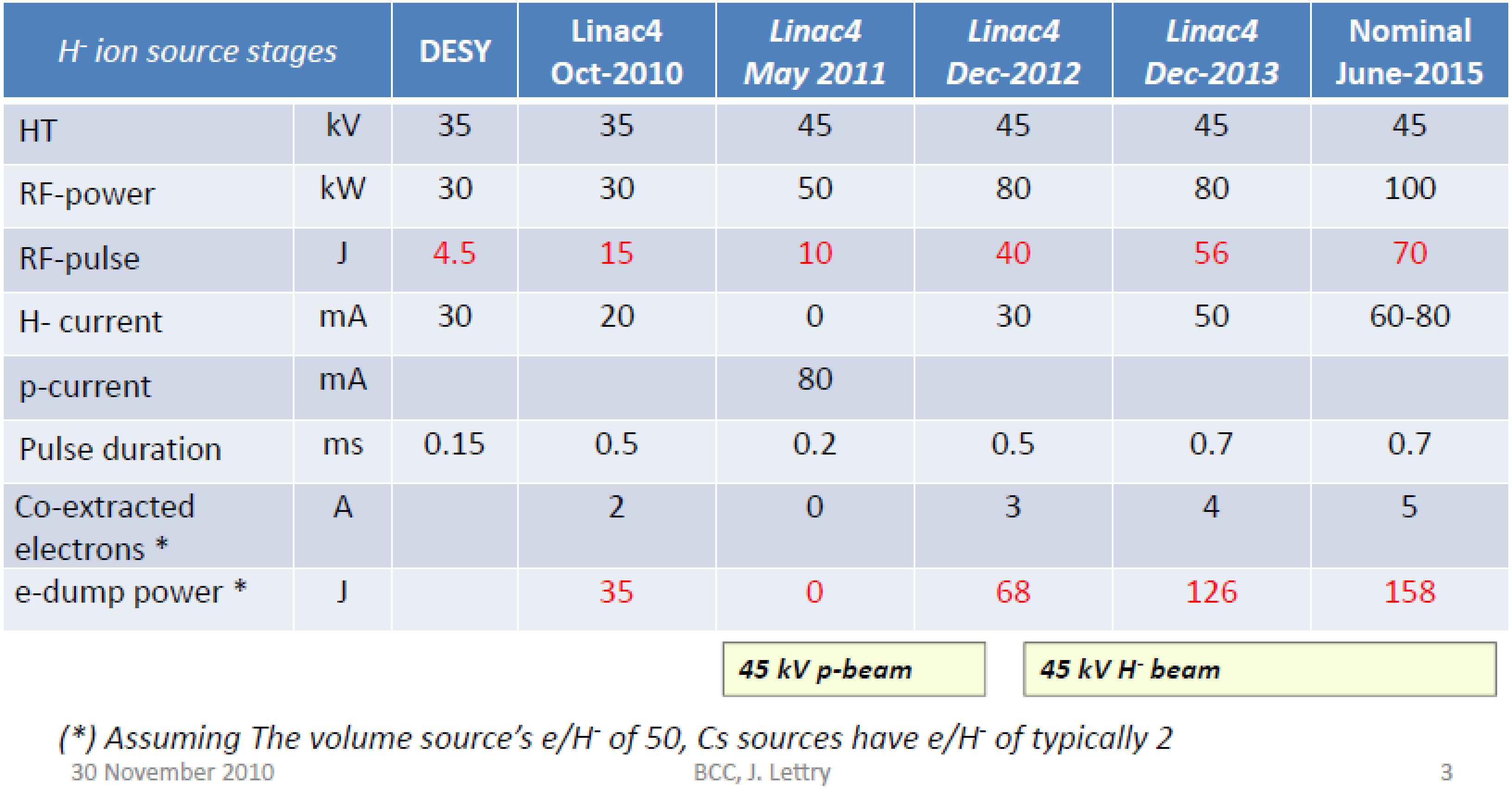
H- source strategy

Need a) a strong program and b) to build up at CERN more competences in H^- sources.

Strategy:
1. Prepare to run the present H^- source with protons for a preliminary commissioning of the RFQ in 2011 (tests already started).
2. Repair and improve the H^- source presently installed at the Test Stand, by steps and in parallel with the operation for the RFQ commissioning and testing.
3. Launch a series of studies for better understanding of the behavior of H^- sources, including the option of cesiation and considering other possible designs.
4. Upgrade the sLHC source test stand (sLHC program will be completed by March 2011) to a full test stand for a Linac4 H^- source (add HV extraction, power supplies, diagnostics, etc.) with as main objective to achieve the nominal H^- beam emittance and reliability.

In the long term, a complete spare source for Linac4 will be commissioned on this test stand for a quick exchange in case of problems.

H- source roadmap



H^- ion source stages		DESY	Linac4 Oct-2010	*Linac4* *May 2011*	*Linac4* *Dec-2012*	*Linac4* *Dec-2013*	Nominal June-2015
HT	kV	35	35	45	45	45	45
RF-power	kW	30	30	50	80	80	100
RF-pulse	J	4.5	15	10	40	56	70
H- current	mA	30	20	0	30	50	60-80
p-current	mA			80			
Pulse duration	ms	0.15	0.5	0.2	0.5	0.7	0.7
Co-extracted electrons *	A		2	0	3	4	5
e-dump power *	J		35	0	68	126	158

45 kV p-beam

45 kV H^- beam

(*) Assuming The volume source's e/H^- of 50, Cs sources have e/H^- of typically 2

30 November 2010 BCC, J. Lettry 3

J. Lettry, 30.11.10

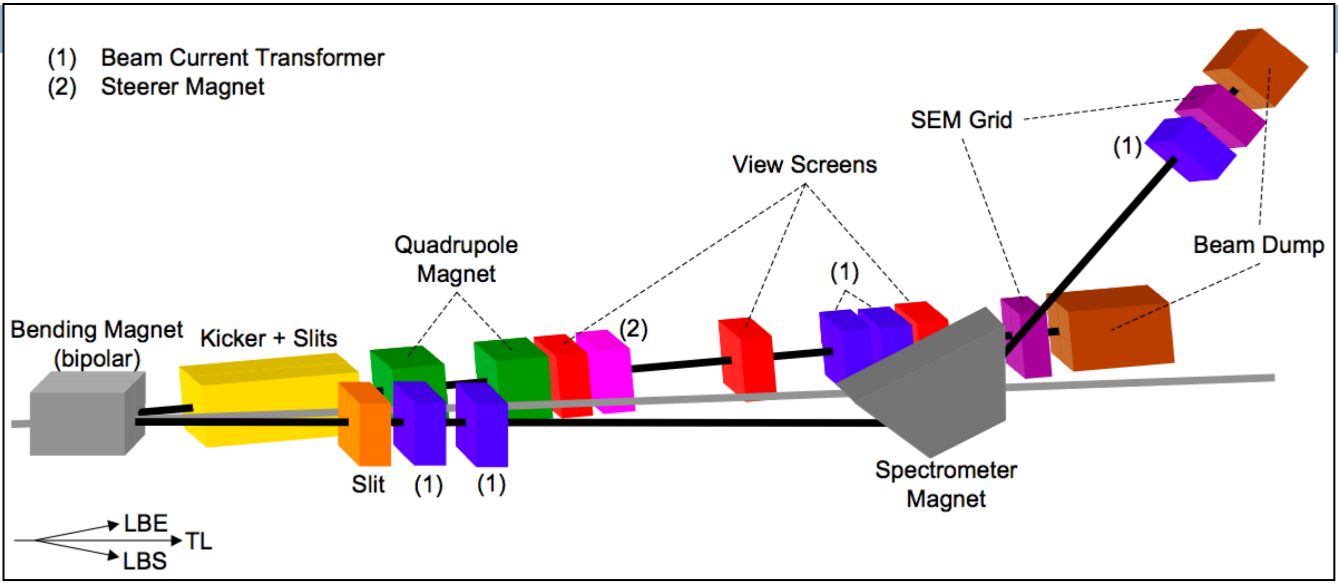
Longer linac pulses

Mitigation #3 for achieving nominal intensities in the PS Booster with lower linac current: take linac pulses longer than the nominal 400 μs and increase # of turns

Answer from W. Weterings and L. Sermeus:

In principle this is possible by adding coils and capacitors to the PFN. Based on the current conceptual design this would give an estimated cost increase of ~ 150Kchf and the decision should be made within 6 month. Nevertheless, this is based on the current conceptual design and some more detailed calculations are required to see if just adding 50% more cells is feasible.

Measurement lines LBE, LBS



- **LBE:**
  - Layout fixed. Compatible with ion operation.
  - Laser scanning done to prepare an integration drawing.
  - Equipment specifications provided; EDMS document released.
- Still to be done before installation:
  - Final screen and camera design (same as for Linac4 dump line), equipment and support drawings and layout.
  - Add water-cooling to quadrupoles, exchange power converters
  - Move steerer dipole.
  - Dump design.
  - Beam pipes.

- **LBS:**
  - Layout proposed, compatible with ion operation. To be adapted in case slit dimensions and equipment positions (dump!) change.
  - Equipment specifications partially provided (depend on final layout); EDMS document on beam dump specifications has been released, slit specifications under approval.
  - Laser scanning done to prepare an integration drawing.
- Still to be done before installation:
  - Propose slit and dump designs, check compatibility with RP restrictions.
  - Finalize SEM grid and spectrometer magnet specifications.
  - Integration drawings needed in addition to layout drawings.
  - Prepare software application.
  - Solve problem of lifting existing/new equipment over BI line.

Performance risk register – cont.

093 A	Manpower - Ion source team - Loss of crucial	BEAM	Loss of crucial staff in the ion source team is possible.		2.00	5.0	25.0	15.0%	3.75	
164	Source intensity and stability	COM	Source intensity and stability might not be sufficient (minimum intensity might be insufficient).		1.00		25.0	15.0%	3.75	
030	RFQ - Failure / Down-time	RF	There is a risk of sparking that might cause possible down-time of the RFQ.			20.0	20.0	15.0%	3.00	22.09.2009: Description of mitigation: * Accelerating the delivery of the ion source for better evaluation of gas load. Cost of mitigation: 1 FTE as additional resource in ion source team
081	Accelerator - Faulty design -	BEAM	Faulty design in the optics.				50.0	5.0%	2.50	
023	Geotechnical / Soil risks	INFRA	Soil investigations have been performed but conditions of the soil might change over time. This becomes critical if occurring more than once per year.	20,000		10.0	30.0	5.0%	2.50	22.09.2009: Description of mitigation: * Closer monitoring of soil conditions.
085	TL - Emittance measurement	BEAM	Simulations for emittance measurements were performed. The risk is that the emittance measurement might not work as expected at the entrance to the booster.		1.00		15.0	15.0%	2.25	23.09.2009: Description of mitigation: * Different type of emittance measurement to be developed. (Prob. of success: 50%) Resp.: U. Raich Cost of mitigation: 200k CHF + 1 FTE
166	Manpower in case of fluctuation	COM	The majority of the work might have to be done by temporary staff. Very specific expertise is needed for commissioning.		1.00		20.0	10.0%	2.00	

+ some 10 other items with lower rating

Linac2 as backup for Linac4

The ultimate mitigation! Dedicated BCC meeting on 29.04.2010:

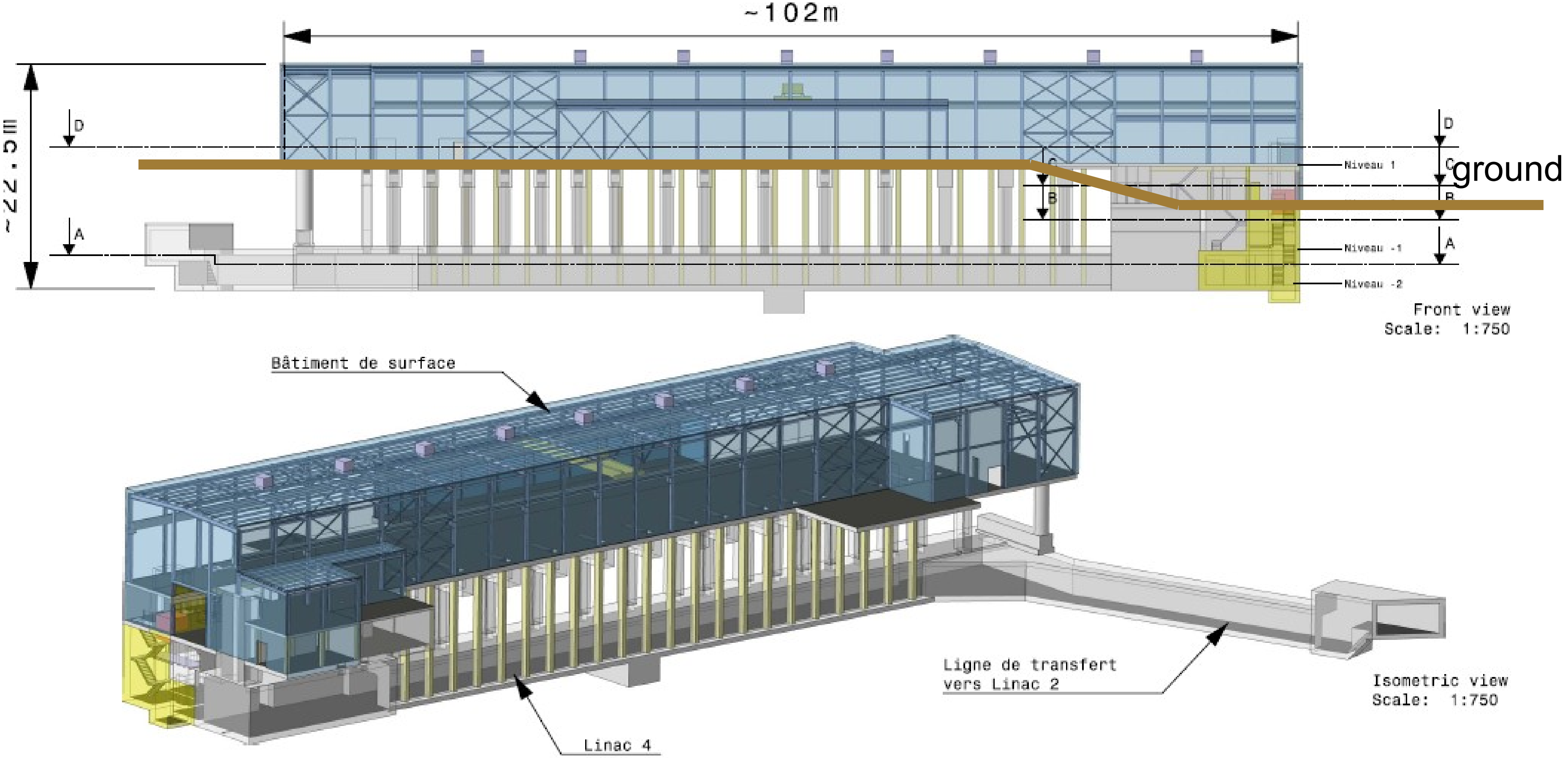
1. The probability of a major accident in Linac4 during the first years of operation (ex.: large fire, damage of accelerating tanks) is relatively low: a) equipment is safer than in the past and modular (limiting damage), b) a long reliability run is scheduled to assess potential problems.
2. In case of a major accident, repair time would be of the order of 6 months (time required for rebuilding 1 to 3 modulators or one RF tank). During this time, the CERN Accelerator Complex can operate with ions from Linac3.
3. The time required to reconnect Linac2 in case of a major accident would be of 4 to 5 months (driven by PSB injection modifications). The personnel involved would receive an important radiation dose. The same time will be needed to reconnect Linac4 once repaired.
4. The impact of keeping the option of reverting to Linac2 is of 1 to 2 additional months required for PSB injection modifications for Linac4 (during the long shutdown) and an additional cost estimated between ~100 kCHF (only cabling and vacuum chambers) and ~1 MCHF (new building for new kicker, distributor and chicane power equipment).

CONCLUSION AFTER THE EVALUATION:
Keeping the option of reverting to Linac2 would allow gaining 1 to 2 months of operation in case of a major accident (with low probability), but would mean losing 1 to 2 months of operation during the Linac4 long shut-down (with 100% probability). Considering as well the dose to personnel for reverting to Linac2, this option should be ruled out.

Conclusions

- Linac4 has a traditional design, but with many new features that can hide potential risks.
- The Linac4 design parameters leave a considerable margin for the standard users (LHC, CNGS, ISOLDE nominal) but are needed for the final high intensity (ISOLDEx2).
- Risks with potential impact on Linac4 performance have been assessed in 2009. The risk of a poor source performance has already materialized, and mitigations have started.
- The option of reverting to Linac2 in case of problems during the operation of Linac4 has been discarded for reasons of time, cost and radiation dose.

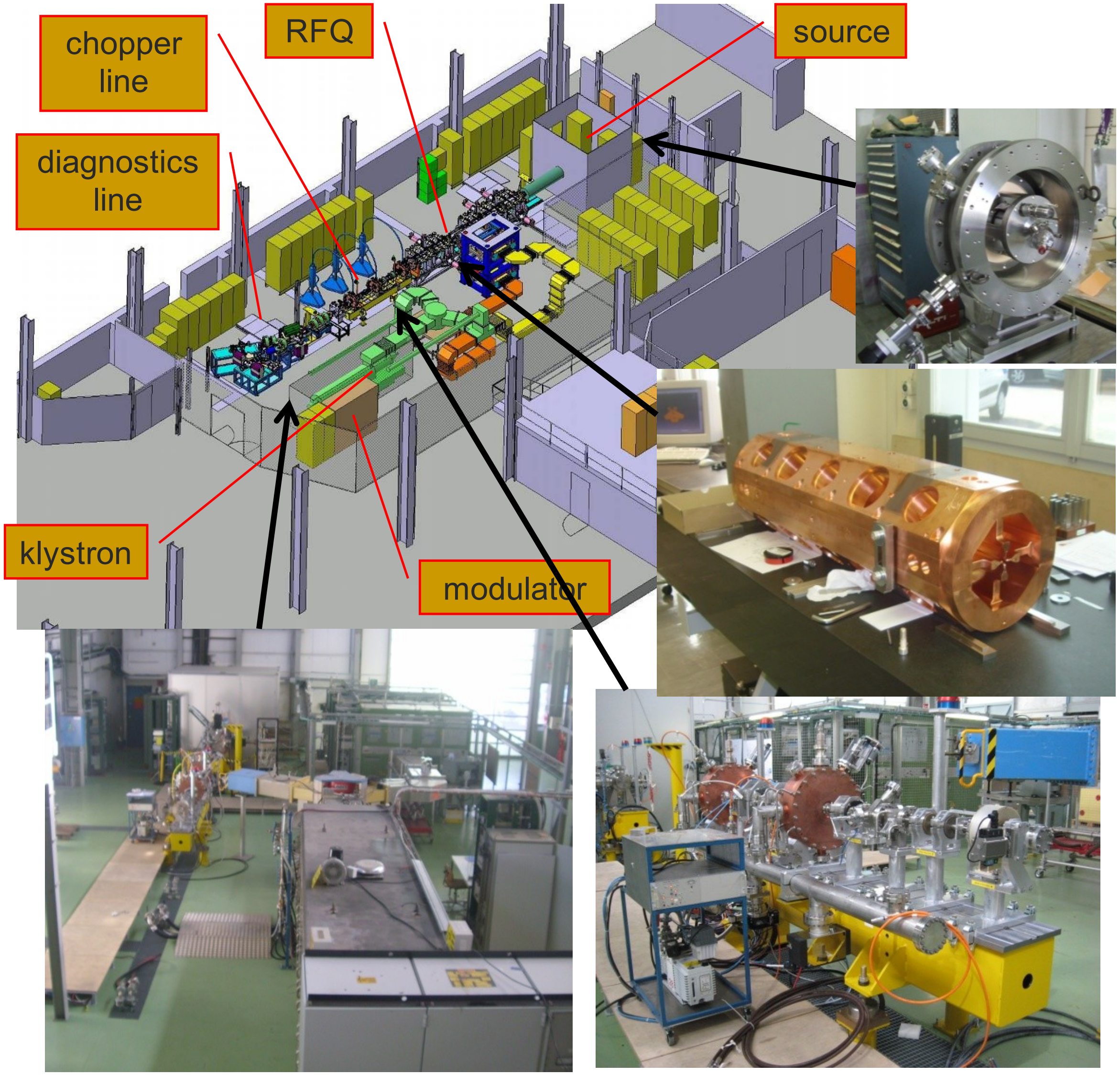
Linac4 civil engineering



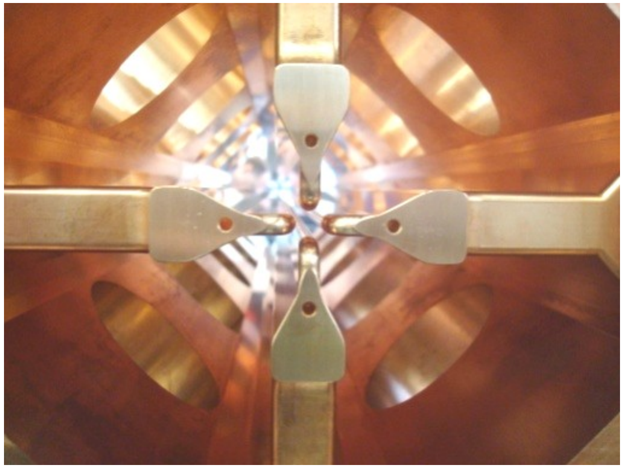
- Design of building started in December 2006.
- Overall floor surface of Linac4 installations = 3’305 m2 (over 4 levels)

Linac4 – Low energy test stand

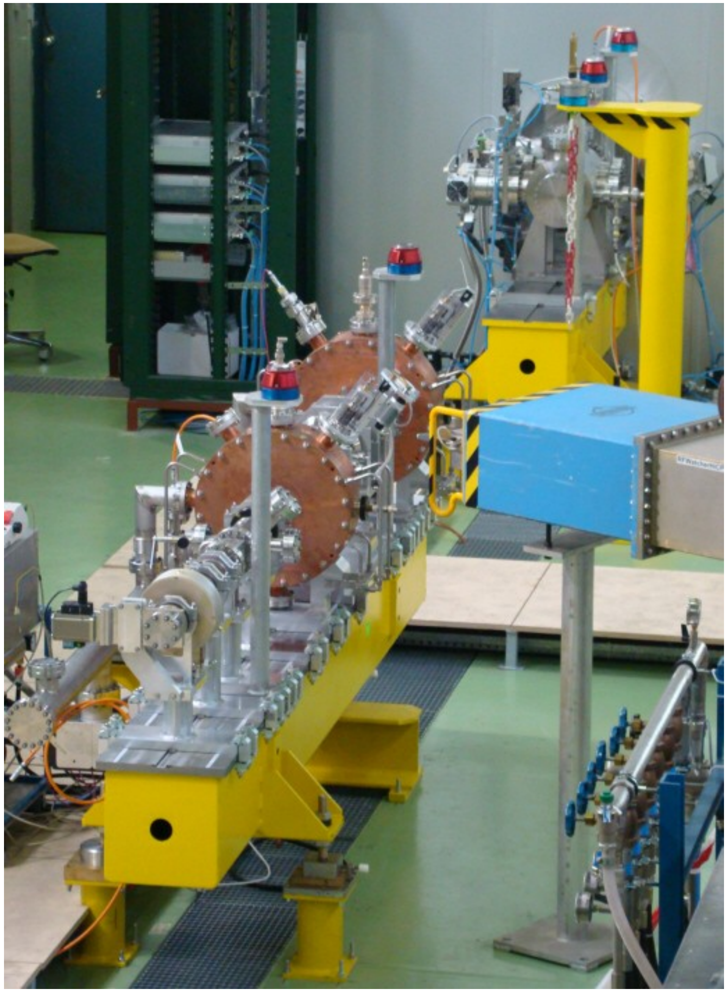
3 MeV TEST STAND in the PS South Hall - will be moved to Linac4 in 2013



- Ion source and LEBT assembled and under test.
- Radio Frequency Quadrupole, in construction at CERN.
- Chopping line built and tested (w/o beam).
- LEP klystron (+ modulator) installed, tested in pulsed op.
- Testing of RF structures at 2 Hz.



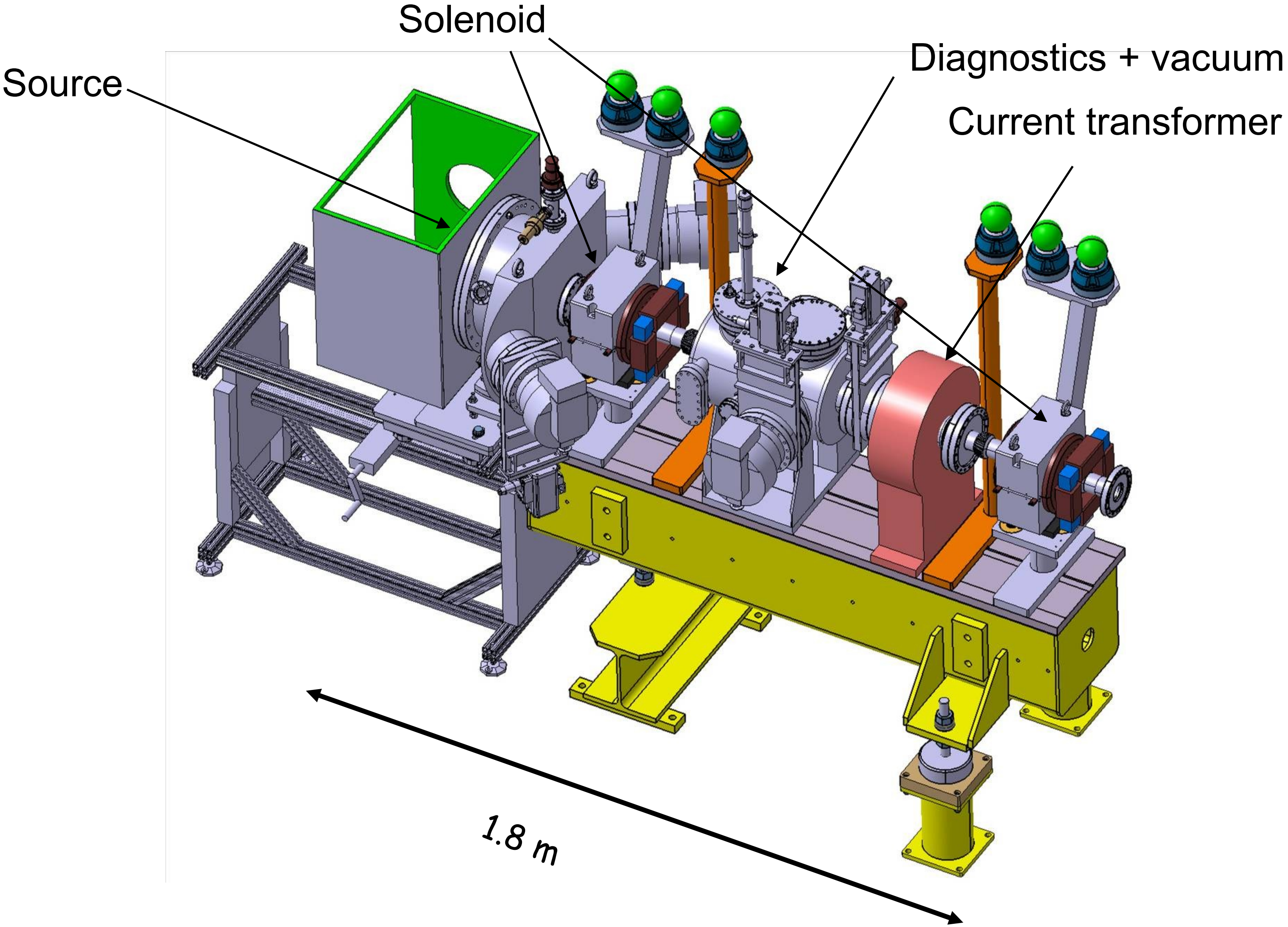
3 MeV Test Stand



Chopper line assembled

LEP-type klystron and prototype modulator under test

Low-Energy Beam Transport



The Linac4 RFQ

module #1

Energy 3 MeV (below radiation threshold)
Length 3m, 3 section of 1 m each.

Brazed 4-vane design. Simplified shape and cooling (max. duty of 10%).

No longitudinal stabilization (length of 3.5λ is ~ maximum achievable with distributed tuners for field correction).

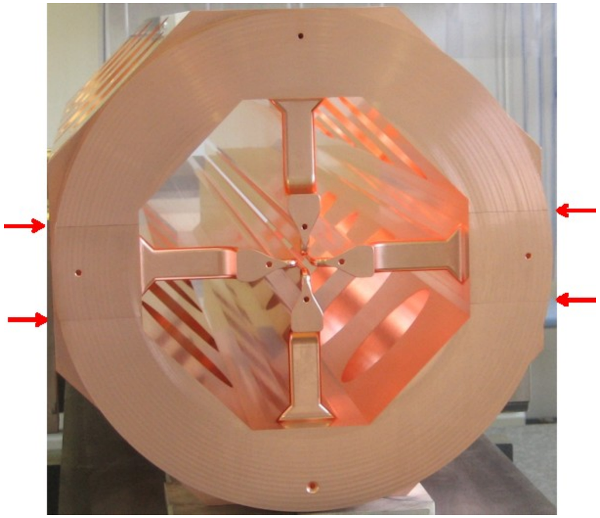
Collaboration with CEA Saclay (in charge of thermal simulations and of RF design, measurement and tuning).

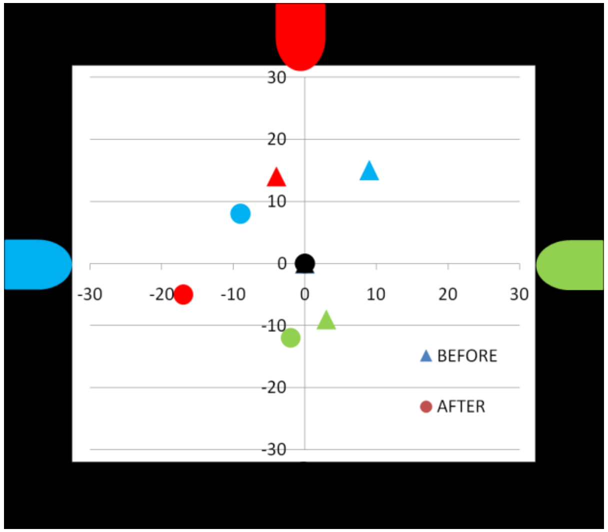
Construction entirely done at CERN: machining, metrology, brazing (horizontal).

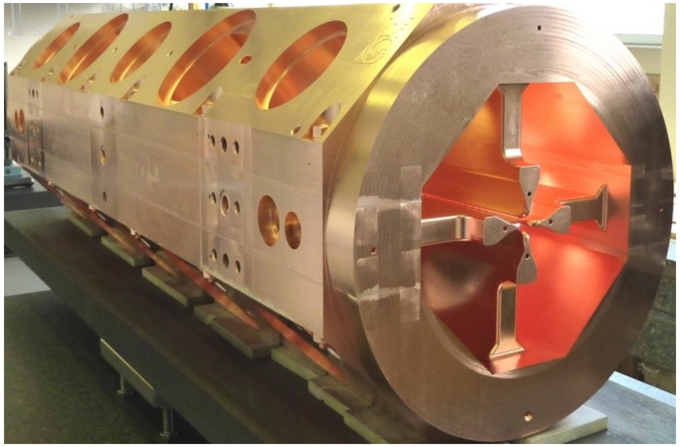
Status: Module #1 completed (2 brazing steps), Module #2 ready for brazing, Module #3 under machining.

RFQ ready for RF tests in June 2011.

Brazing of the 1st RFQ Module



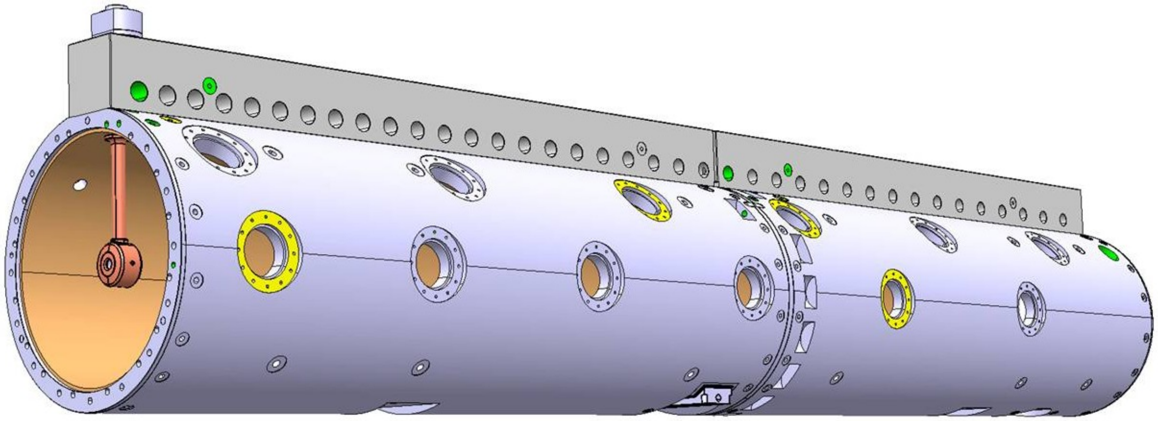


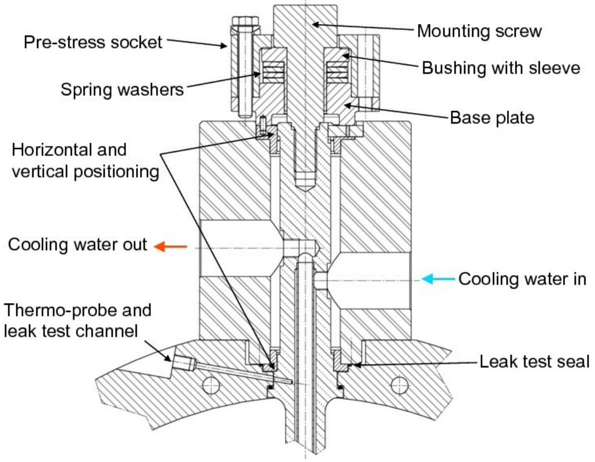


Deformations <25 μm (tolerance 30 μm).

Linac4 – Drift Tube Linac

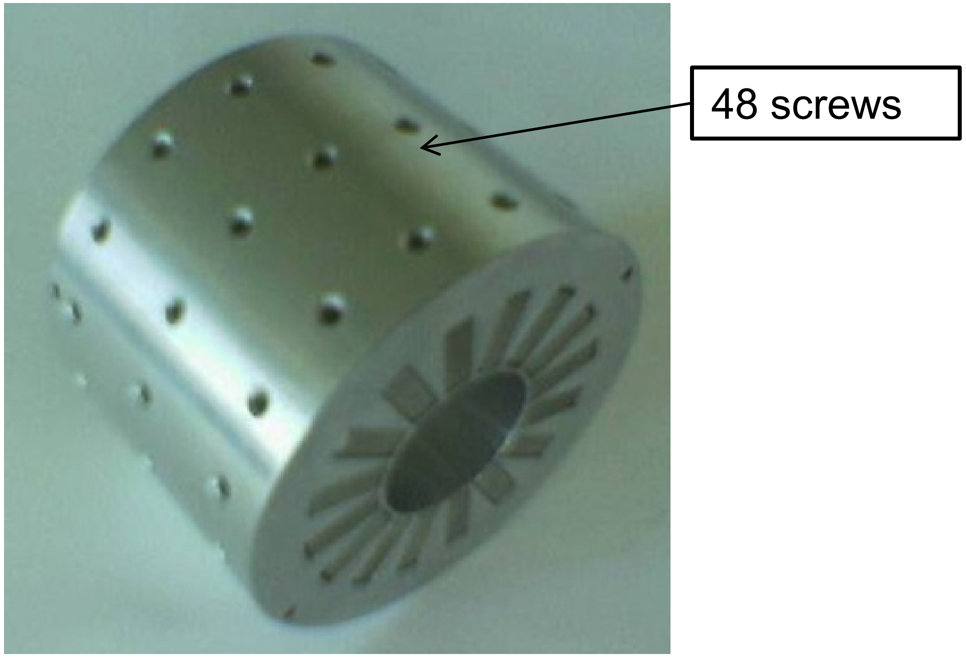
- 3-50 MeV, 3 tanks.
- Design Completed and tested on a prototype (1m, 12 drift tubes) at full RF power (10% duty cycle).
- Main features: DTs rigidly mounted on a girder, with special mounting mechanism, only metallic joints and no adjustment. Tank in Cu-plated Stainless steel. Permanent Magnet Quadrupoles in vacuum.
- Construction started (DTs with ESS-Bilbao).
- Tank1 ready for test in 2011.

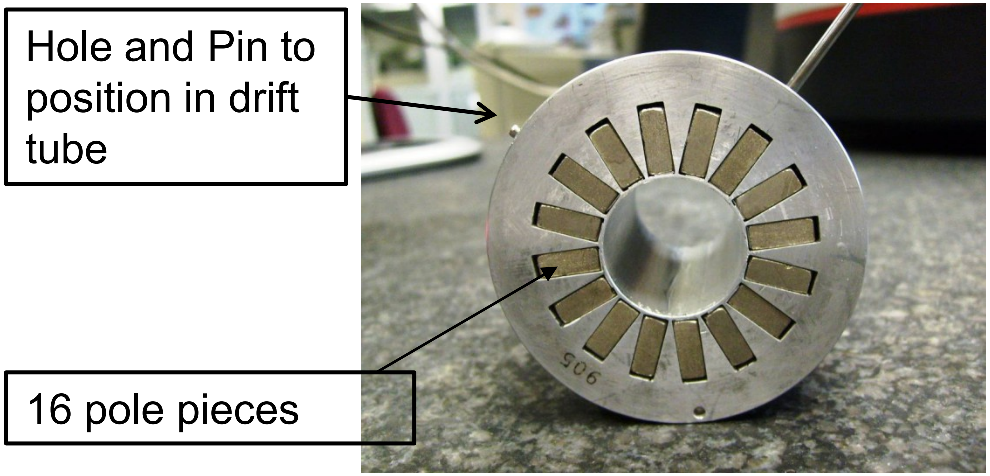




Important improvements with respect to present DTL linacs

PMQs for the DTL

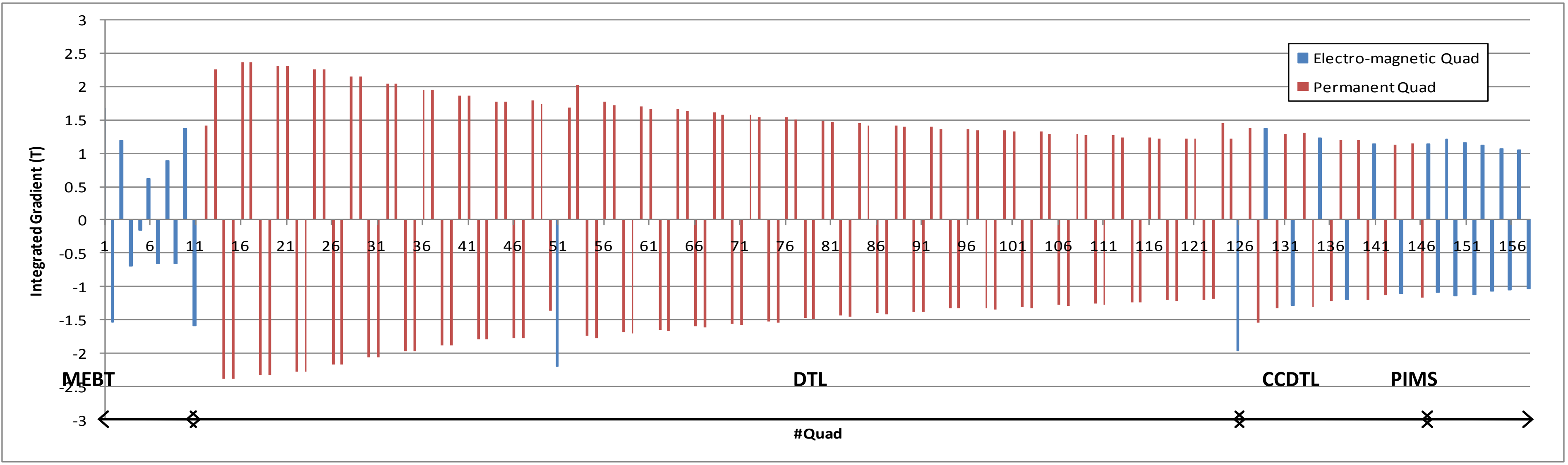




- **One PMQ installed in each Drift Tube**
  - FFDD system
  - Max/Min integrated gradient= 2.4/1.2 T
  - Tolerance : ±0.5% on the field, 1mrad on the roll, harmonics <0.01 at 75%radius,
- **Magnet Material - Samarium Cobalt** (Sm_2Co_{17})
  - PM material selected to minimize field strength loss due to neutron fluence.
- **Housing Material - Stainless Steel** (316LN)
  - For use in vacuum (low degassing)
  - Stable against corrosion (galvanic couple with copper)
  - Thermal expansion coefficient similar to copper
  - Low conductivity protects against accidental heating during the welding process
- **Installation in Drift tube**
  - Each PMQ will be positioned in the centre of the drift tube, oriented with a dowel pin and clamped in position by a spring washer
  - The drift tube will not have a full bore tube and the end-caps, located on the PMQ, will be welded to the body of the drift tube after positioning of the PMQ.

Quadrupoles for LINAC4

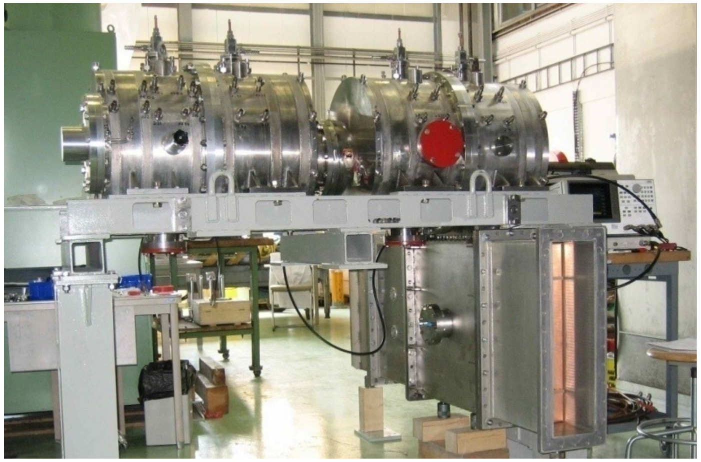
- Majority of focusing elements are permanent quadrupoles (136 PMQ and 31 EMQs in the linac).
- 3 families
  - 45 mm long , 22/60 inner/outer diametre in to be housed in drift tubes oftank1
  - 80 mm long , 22/60 inner/outer diametre to be housed in drift tubes tank2and3
  - 100mm long 45/124 inner/outer diametre in CCDTL intertanks (outside beam pipe)

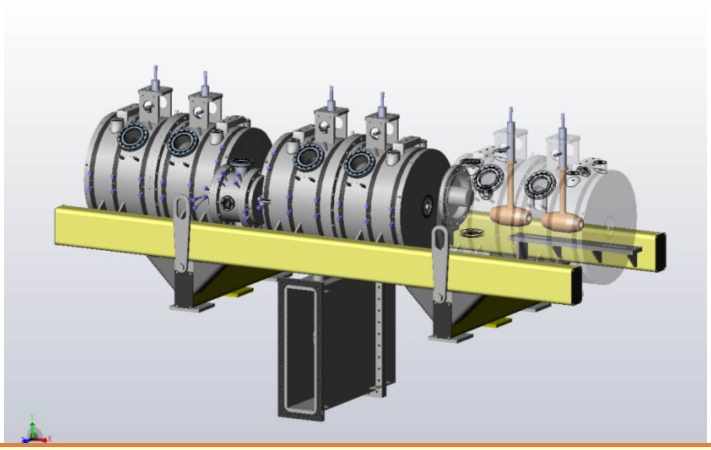


Integrated Gradient of the quadrupoles along linac4

Linac4 – Cell-coupled DTL

- 50-100 MeV, 7 modules of 3 tanks each.
- Design completed and tested on a prototype (2 tanks, 4 drift tubes) at full RF power (10% duty cycle).
- Main features: Focusing by PMQs (2/3) and EMQs (1/3) external to DTs. Tanks with 2 DTs connected by coupling cells.
- Construction started at VNIITF (Snezinsk) and BINP (Novosibirsk) in January 2010.
- Module#1 to be delivered to CERN for testing in January 2011.

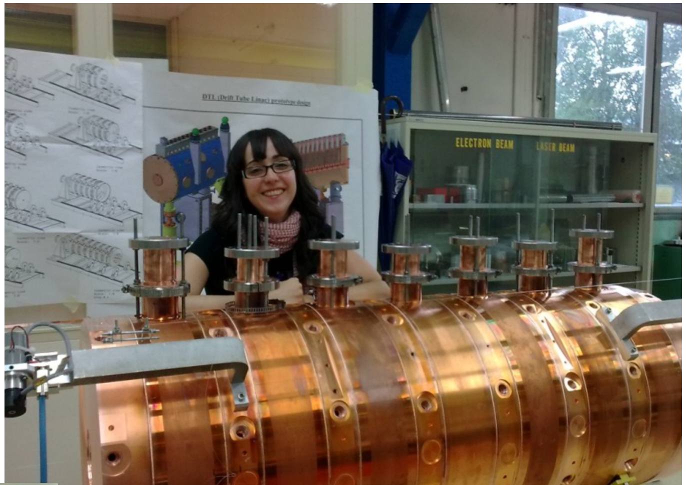


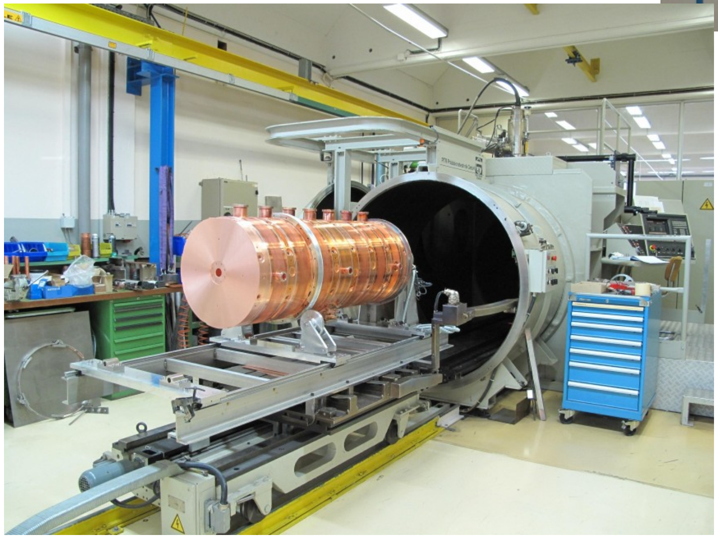


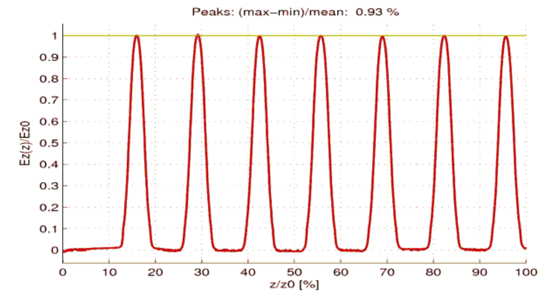
Structure used for the first time in a particle accelerator

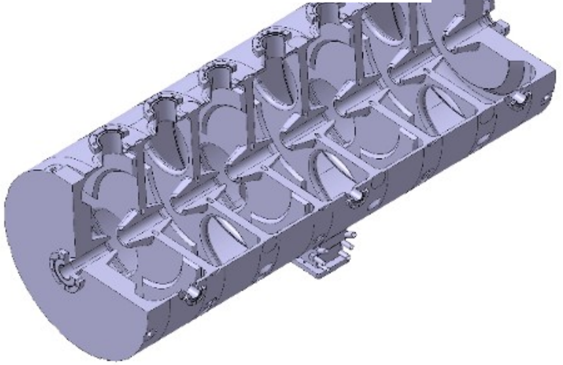
Linac4 – Pi-Mode Structure

- 100-160 MeV, 12 tanks of 7 cells each.
- Design completed, tank #1 completed and tuned, tested at full RF power.
- Main features: Focusing by external EMQs, tanks of 7 cells in pi-mode. Full-Cu elements, EB-welded.
- Construction will start beginning 2011 in collaboration with Soltan Institute (Warsaw) and FZ Julich.







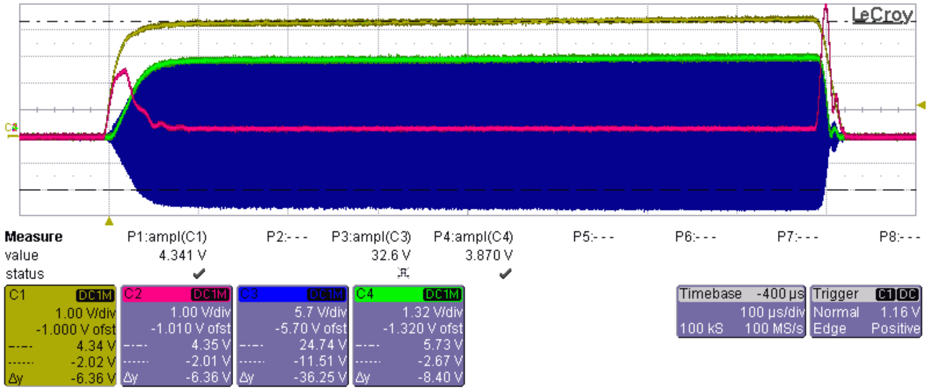


Structure used for the first time in a proton accelerator

The PIMS hot prototype

PIMS high-power conditioning

- cavity #1, length 1.4 m, weight ~700 kg
- ZT^2: 26.5 MΩ/m (95% of HFSS calculation)
- cell to cell coupling k: 5.6% to 4.8%
- $E_{S,max}$ = 1.8 Kilpatrick (33.2 MV/m @ 352MHz)

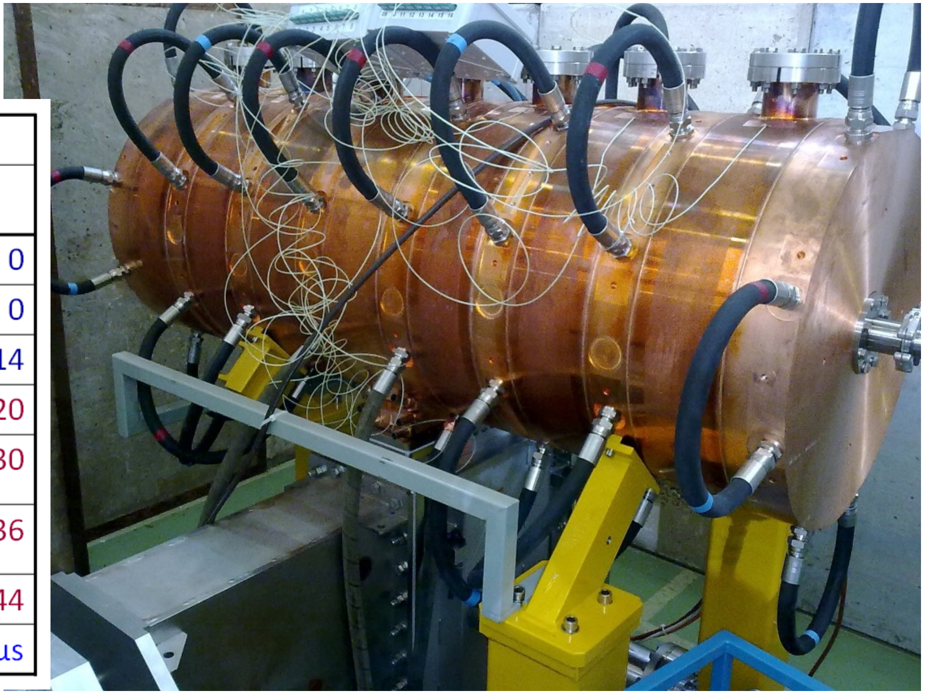


Measure	P1:ampl(C1)	P2:- - -	P3:ampl(C3)	P4:ampl(C4)	P5:- - -	P6:- - -	P7:- - -	P8:- - -
value	4.341 V		32.6 V	3.870 V				
status	✓			✓				

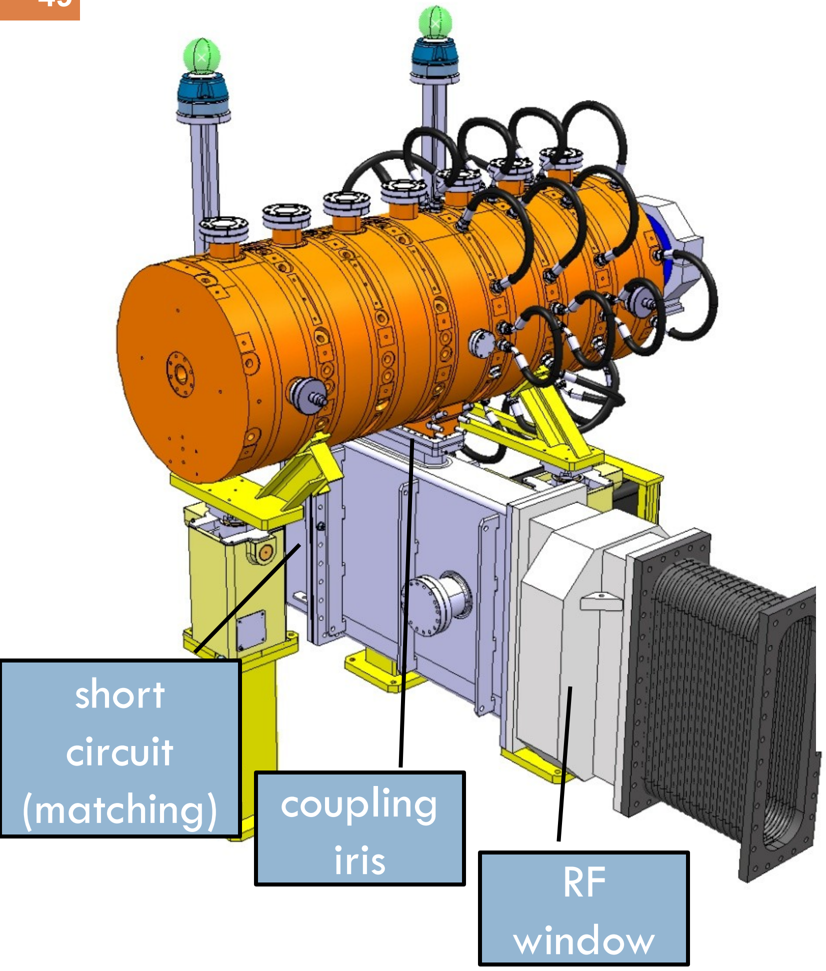
C1 DC1M	C2 DC1M	C3 DC1M	C4 DC1M
1.00 V/div	1.00 V/div	5.7 V/div	1.32 V/div
-1.000 V ofst	-1.010 V ofst	-5.70 V ofst	-1.320 V ofst
-·-·- 4.34 V	-·-·- 4.35 V	-·-·- 24.74 V	-·-·- 5.73 V
······ -2.02 V	······ -2.01 V	······ -11.51 V	······ -2.67 V
Δy -6.36 V	Δy -6.36 V	Δy -36.25 V	Δy -8.40 V

Timebase -400 µs	Trigger C1 DC
100 µs/div	Normal 1.16 V
100 kS 100 MS/s	Edge Positive

day	T_{RF}	com.	P_{peak}	T_{pulse}	vacuum	X-ray $_{axis}$	X-ray$_{ext}$
2010	[h]			[µs]	[mbar]	[mSv/h]	[µSv/h]
2.11.	2	setup	1 kW	800	$5 \cdot 10^{-6}$	0	0
3.11.	6	multipactor	1 .. 10 kW	25	$8 \cdot 10^{-6}$	0	0
4.11.	6		700 kW	180	$8 \cdot 10^{-6}$	12	14
5.11.	2	modulator	700 kW	300	$4 \cdot 10^{-6}$	15	20
8.11.	4	roof, temp. sens.	700 kW	500	$1 \cdot 10^{-6}$	17	30
9.11.	5	trigger, temp.	~ 500 kW	800	$8 \cdot 10^{-7}$	17	36
10.11.	3		700 kW	800	$1 \cdot 10^{-6}$	25	44
sum	28	cavity conditioned to P_{peak}= 700 kW, f_{rep}=2 Hz, T_{pulse}=800 µs					



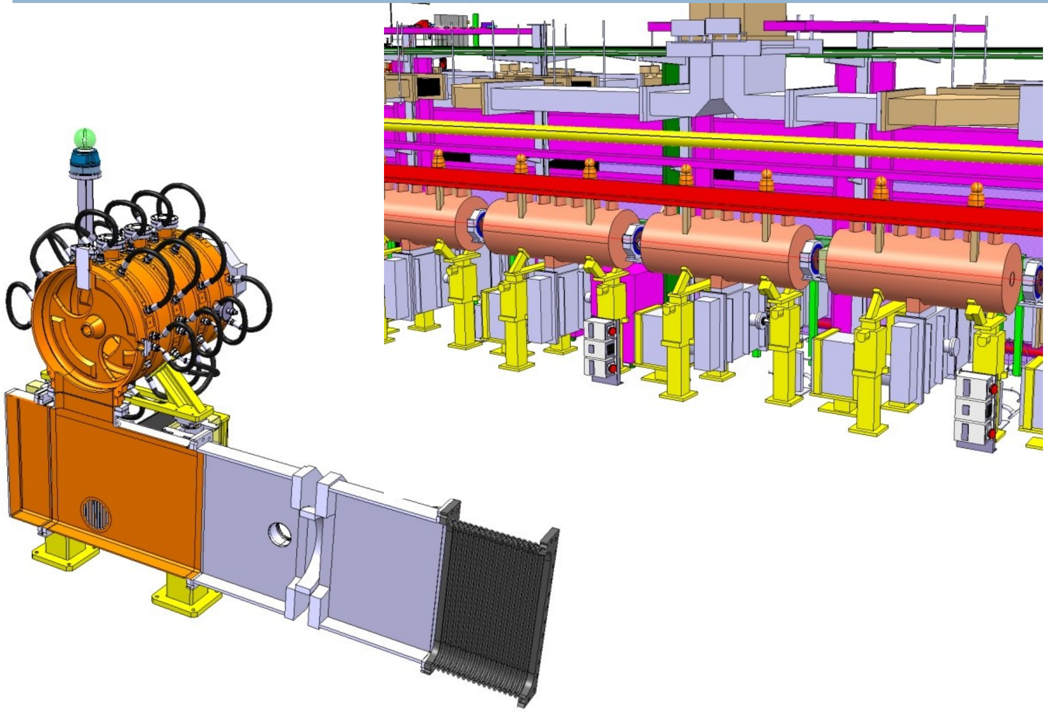
Linac4 RF coupler design



short circuit (matching)

coupling iris

RF window



Coupling to a tangential waveguide closed by a short circuit at λ/4 from the iris

Simple, reliable, cheap

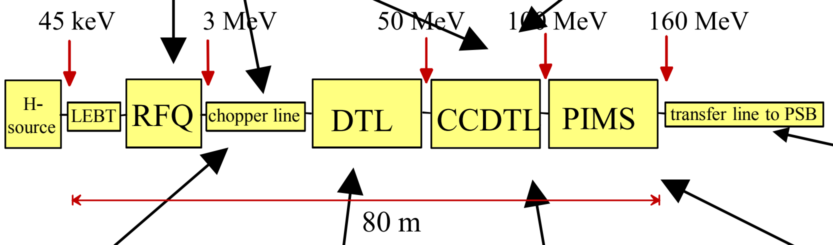
Linac4 – External Contributions

Network of agreements to support Linac4 construction. Relatively small fraction of the overall budget, but access to specialized manpower ! Integration at the component level.

RFQ RF design, RF amplifiers, modulator construction from French Special Contribution. *started.*

Prototype modulator, RF tuners, couplers, waveguides from India, *in progress*

Agreement with DESY to access drawings of H- source *completed*



Transfer line vacuum chambers and supports from Pakistan, *agreed*

Chopper line built in a EU Joint Research Activity *completed*

Participation of ESS-Bilbao in DTL construction, *started*

Construction of CCDTL in Russia, via an ISTC Project *started*

Collaboration agreement with Soltan Institute (Poland) and FZ Julich (D) for PIMS construction, *in preparation.*

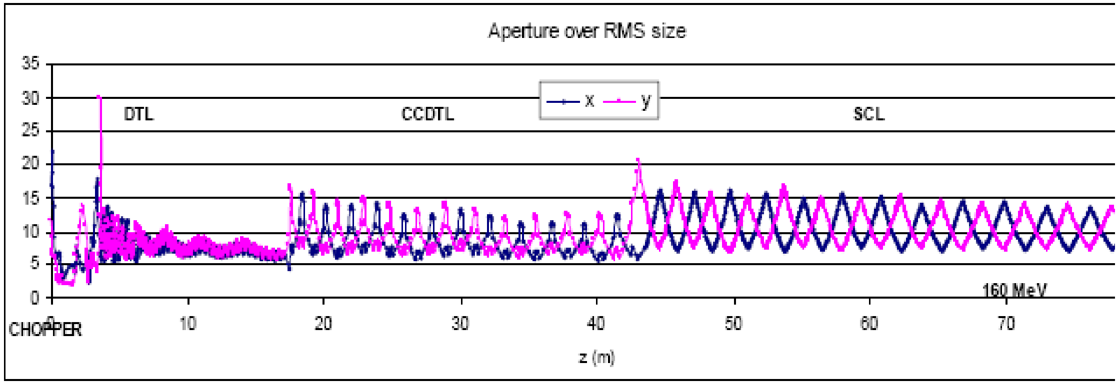
Linac4 – linac beam dynamics

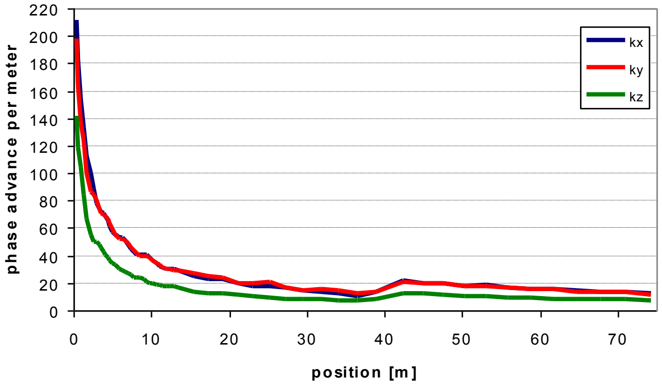
Beam optics design to minimize beam loss and emittance growth for:

1. Low activation (in particular for high duty cycle operation).
2. Minimum emittance growth for painting into the PSB acceptance.
3. Losses on concentrated spots (collimation).

LINAC4 BEAM DYNAMICS DESIGN for beam loss < 1W/m at high beam power:

1. Smooth phase advance transitions.
2. Operating point far from resonances.
3. Longitudinal to transverse phase advance ratio 0.5-08 (no emittance exchange).
4. Smooth variation of transverse and longitudinal phase advance.
5. Large apertures (> 7 rms beam size)





Linac4 - reliability

Reliability (specially in the first years!) will be a challenge for a machine that has to provide beam to all CERN machines.

Linac2: ~6000 hours/year with fault rate ~1.5%.

Main approach:

-Prefer simple systems, with minimum number of components.

-Standardized equipment (as much as possible).

-Provide safety margins in the design.

-Prepare failure scenarii (to be applied in case of problems).

-Foresee a test period before connection to the PS Booster.

-Provide a sufficient number of spares.