Introduction to Linac4

M. Vretenar

1. Motivations
2. Parameters, Architecture, Schedule, Organisation
3. Requirements for the ion source

Ion Source Review

07.06.2011

Upgrading LHC Luminosity

	Luminosity ($cm^{-2}s^{-1}$)	Beam intensity @ injection (*)
Present (May 2011)	~2 $x10^{33}$	
Nominal	10^{34}	1.1 $x10^{11}$
Upgraded	~5 $x10^{34}$	~2.4 $x10^{11}$

(*) protons per bunch, in 3 μm emittance

expected

requires upgrade of both LHC and injectors, to be achieved by 2020

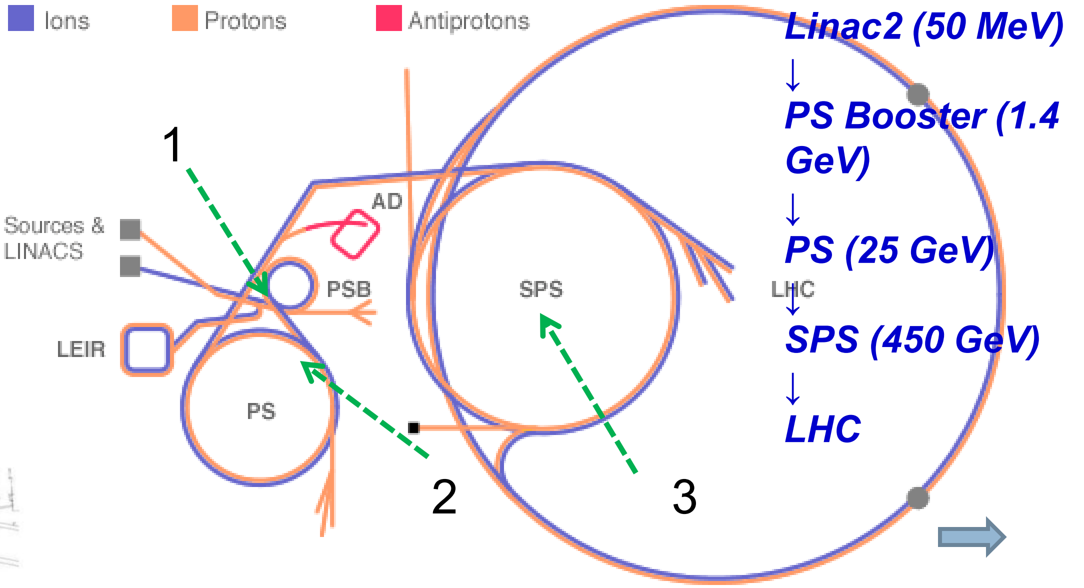
At the moment, the injectors can provide only the intensity required for the nominal luminosity

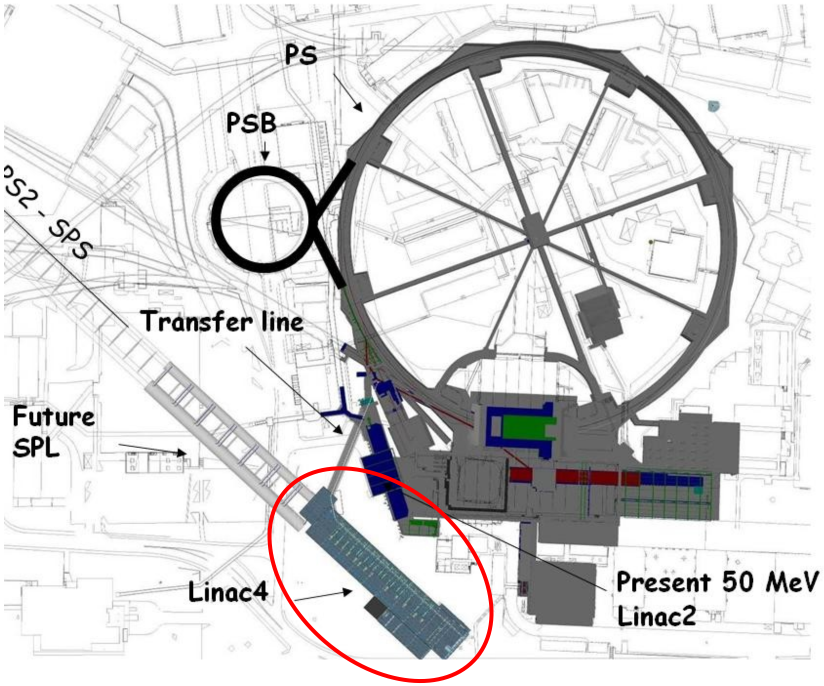
Need a powerful upgrade program to reach ~5 $x10^{34}$, to be completed by 2020.

Limitations to injector intensity

Three bottlenecks identified for higher intensity from the LHC injectors:

1. Space charge tune shift at PSB injection (50 MeV).
2. Space charge tune shift at PS injection (1.4 GeV).
3. Electron cloud and other instabilities in SPS.





Low injection energy into the PSB is the first and most important bottleneck →

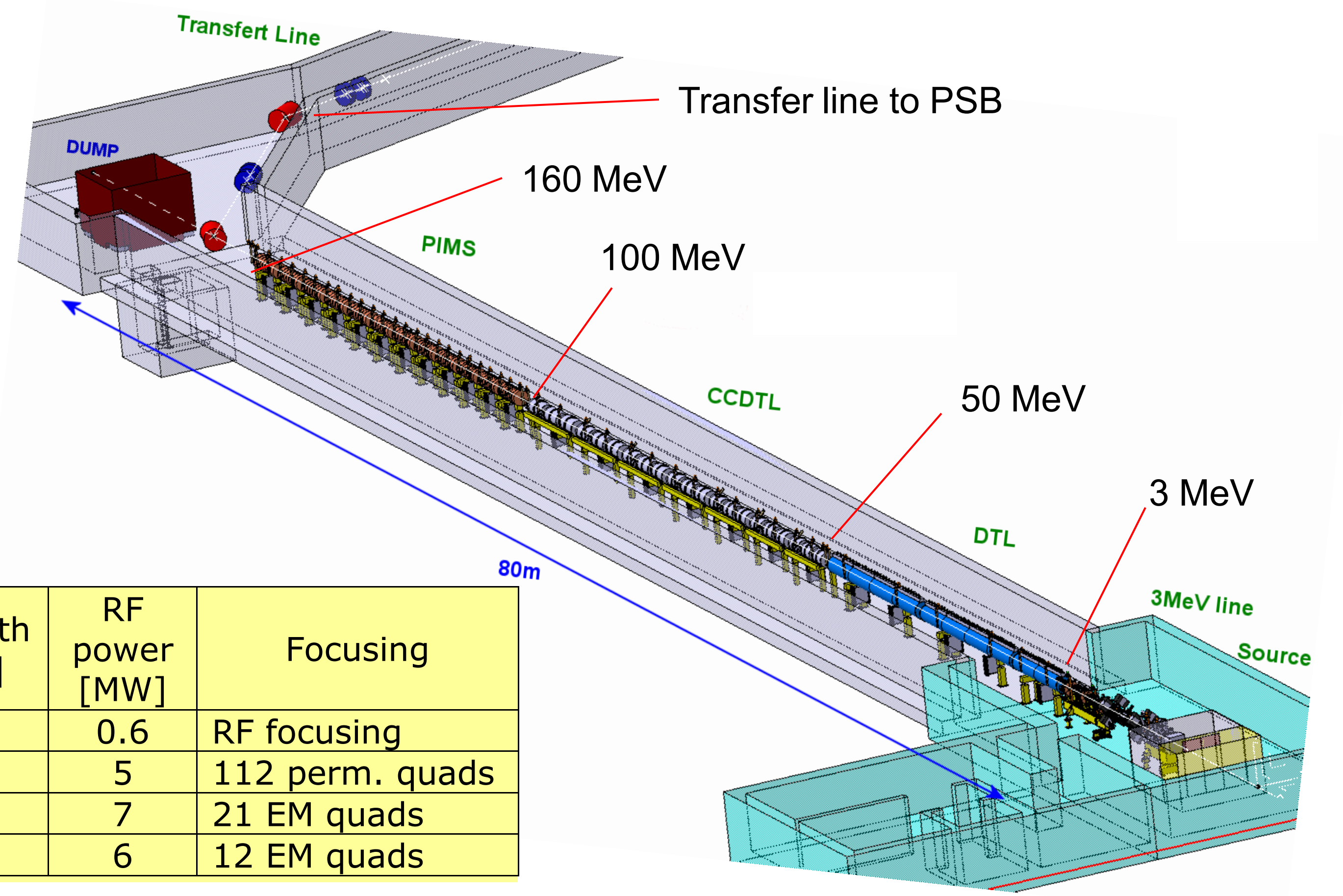
Decision (CERN Council, June 2007) to build a new linac (Linac4) to increase energy from 50 to 160 MeV and go to H- injection in the PSB.

Linac4 is positioned in one of the last “free” areas on the CERN Meyrin site, providing easy connection to the PSB and the option of a future extension to higher energy (SPL, 4 GeV).

Linac4 layout

- Conventional (normal-conducting) layout:

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.



Linac length ~ 80 m

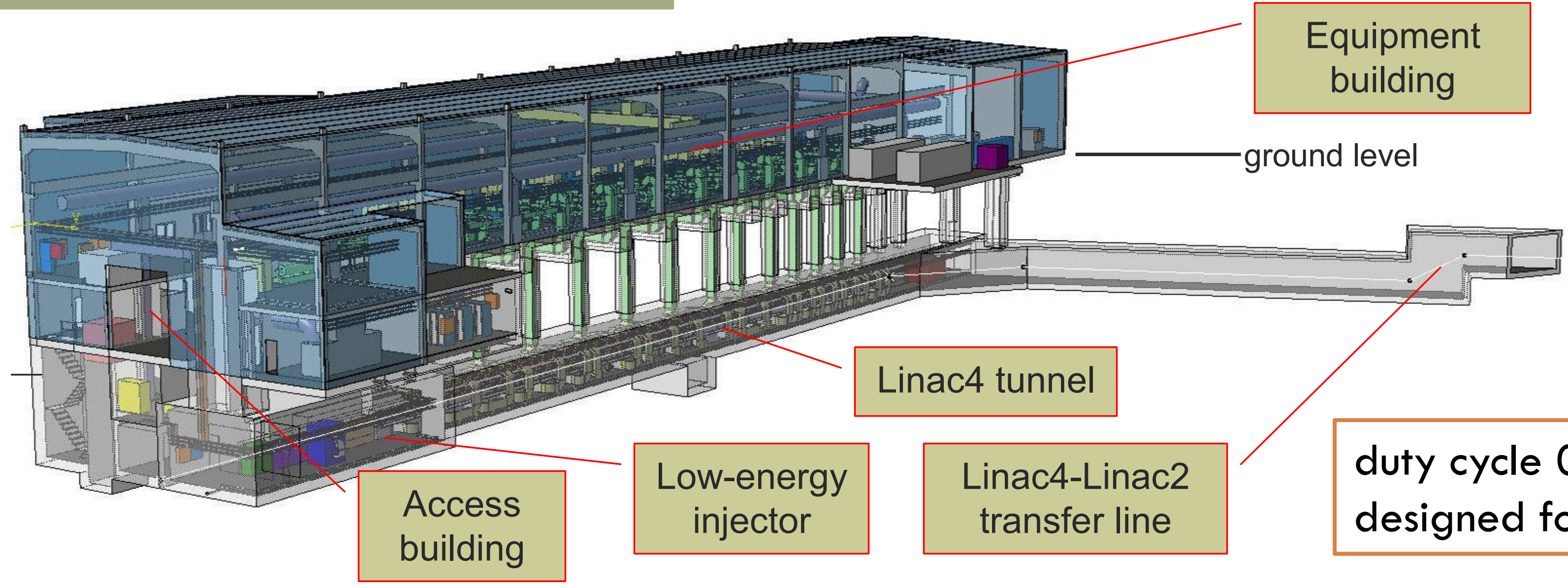
	Energy [MeV]	Length [m]	RF power [MW]	Focusing
RFQ	0.045 – 3	3	0.6	RF focusing
DTL	3 – 50	19	5	112 perm. quads
CCDTL	50 – 102	25	7	21 EM quads
PIMS	102 – 160	22	6	12 EM quads

Linac4 – basic parameters

1. Higher intensity in PSB for the LHC upgrade.
2. More modern and sustainable machine than Linac2 (worries for long-term operation of Linac2 – vacuum, RF).
3. Flexible operation and reduced loss with new technologies (chopping, H- injection).
4. Higher intensity for non-LHC users.
5. Prepare for a possible high-intensity upgrade (neutrino facility).

Note: Linac3 is the heavy-ion linac!

- ☞ 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 2 Hz (1.1 Hz max. PSB), possible future upgrade to 50 Hz.
- ☞ Beam current 40 mA in 400 μs: >2 present PSB maximum with 100 turns injection in PSB.



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

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
Tr. emittance (source)	0.25	π mm mrad
Tr. emittance (linac exit)	0.4	π mm mrad

Max. repetition frequency for accelerating structures 50 Hz

1.1 Hz maximum required for injection in the PSB

Chopping at low energy to reduce beam loss at PSB.

- Structures and klystrons dimensioned for 50 Hz.
- Power supplies, electronics, cooling and electricity) dimensioned for 2 Hz.

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 reliable high efficiency RF structures

- **Linac beam dynamics**

  emittance preservation, low loss design for possible high-duty operation

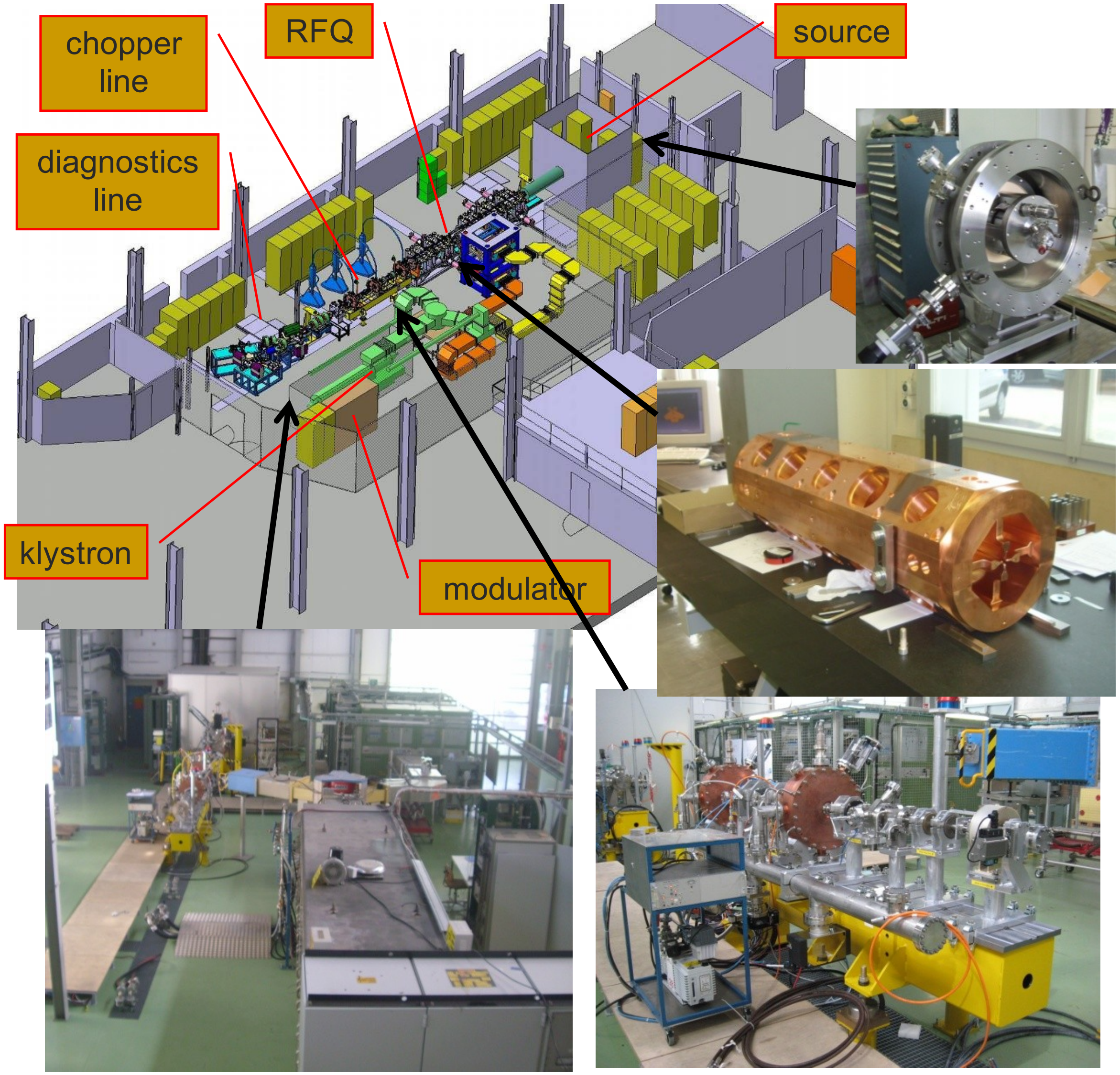
- **PSB injection**

  4-ring stripping, beam optics

- **Reliability**

  benchmark: present availability of Linac2 is 98.5%!

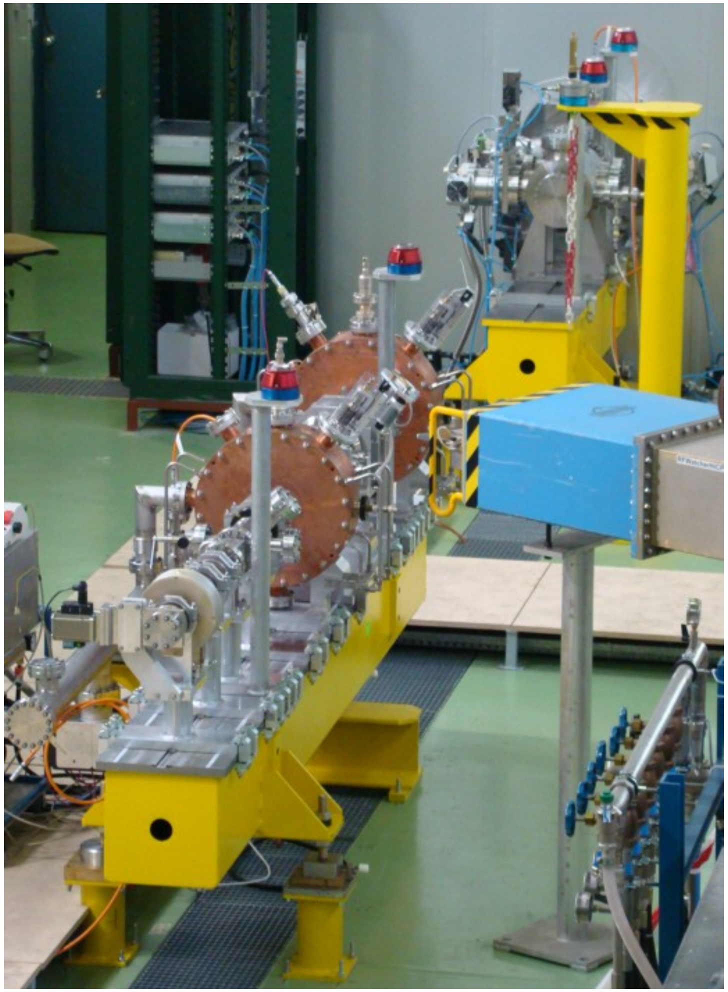
Linac4 – Low energy test stand



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

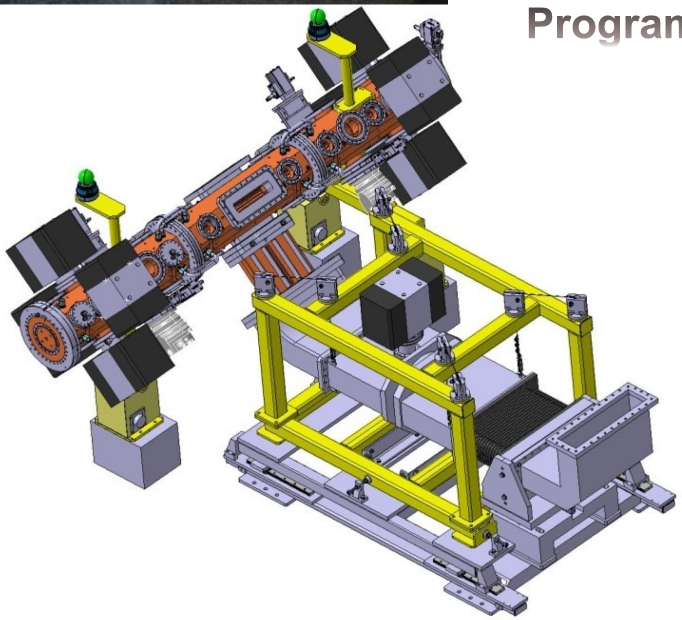


Chopper line assembled

LEP-type klystron and prototype modulator under test

The Linac4 RFQ

module #3



Energy 3 MeV, length 3m, 3 section of 1 m each.

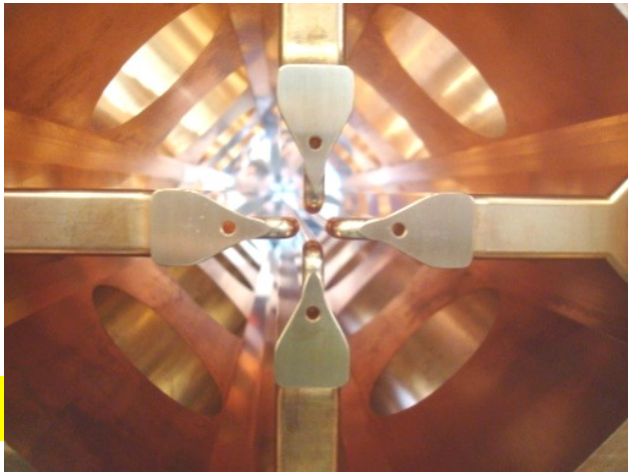
Brazed 4-vane design with simplified shape and cooling, for max. duty cycle 10%.

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

Status: Modules #1 and #2 completed (2 brazing steps), Module #3 under final machining (brazings in June/July 2011).

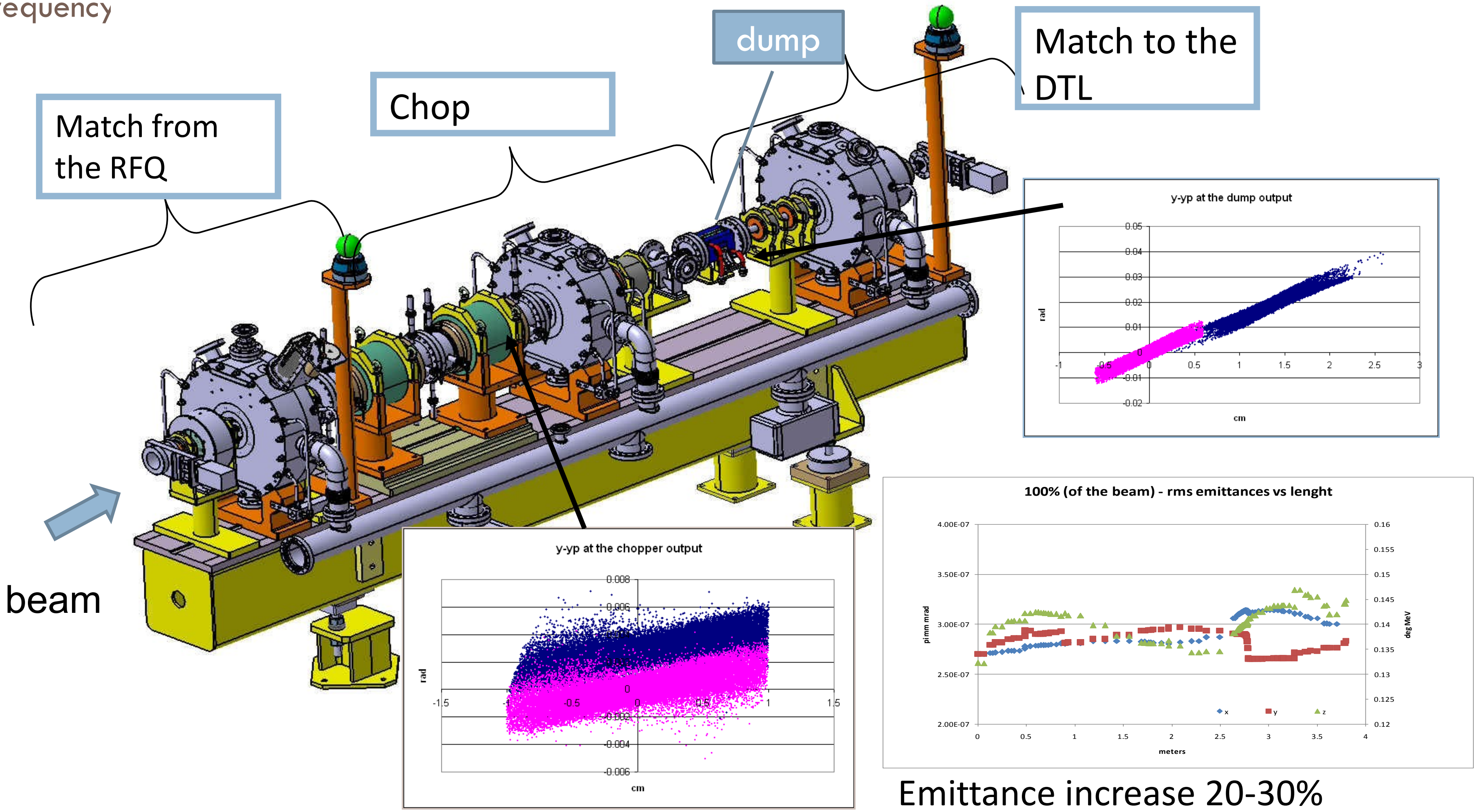
Program: RF tests in September/October 2011,
RF conditioning October/November 2011,
First beam end 2011.

module #1



Chopping

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



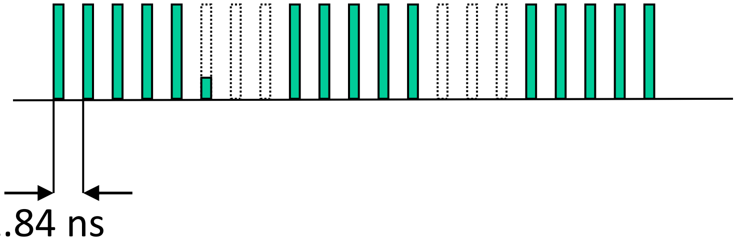
Emittance increase 20-30%

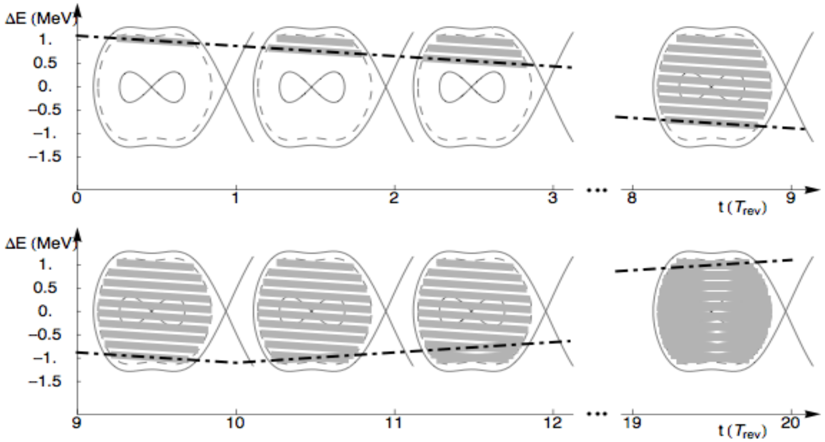
Chopper line layout

Length 3.6 m

Already completed, installed in the test stand and tested without beam.

Chopper: 2 meander-line structures on ceramic substrate.





PSB injection scheme (with energy ramping)

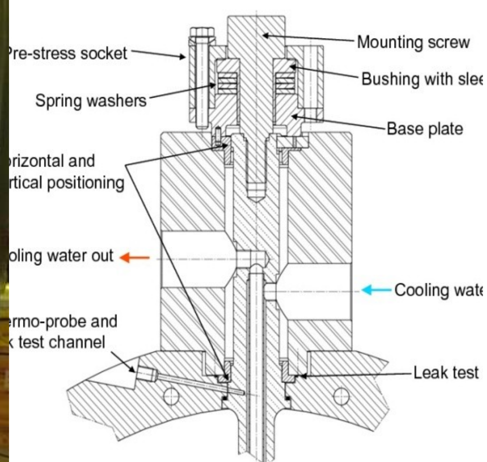
Accelerating structures - 1

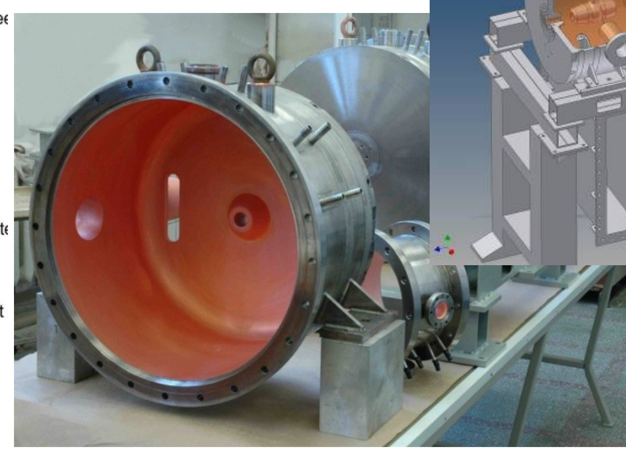
DTL (Drift Tube Linac)

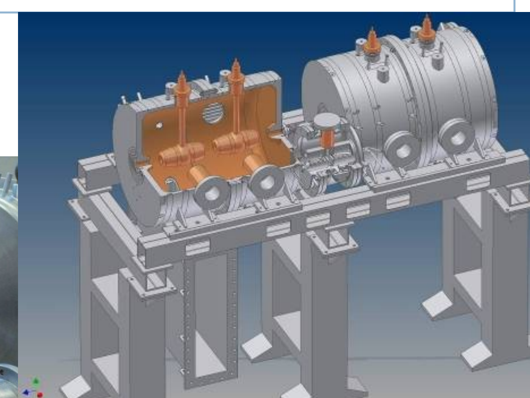
- 3-50 MeV, 3 tanks.
- Permanent Magnet Quadrupoles in vacuum.
- New design for DTs mounting mechanism (no bellow or O-rings).
- Prototype (1m, 12 drift tubes) fully tested.
- Construction started.
- Tank1 ready for test at end 2011.

CCDTL (Cell-Coupled DTL)

- 50-100 MeV, 7 modules of 3 tanks each.
- Prototype (2 tanks, 4 DTs) fully tested.
- Focusing by PMQs (2/3) and EMQs (1/3) external to DTs. Tanks with 2 DTs connected by coupling cells.
- Construction started (Russian collaboration).
- Module 1 and 2 to be delivered 10/2011.



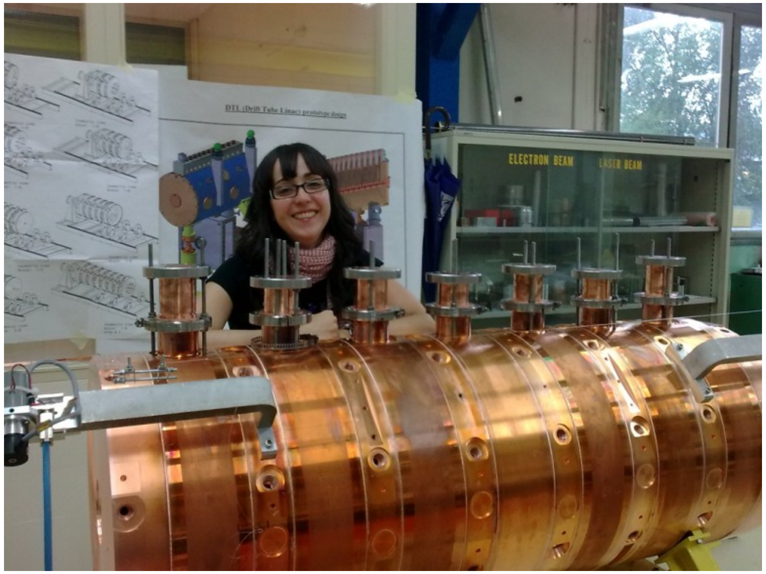


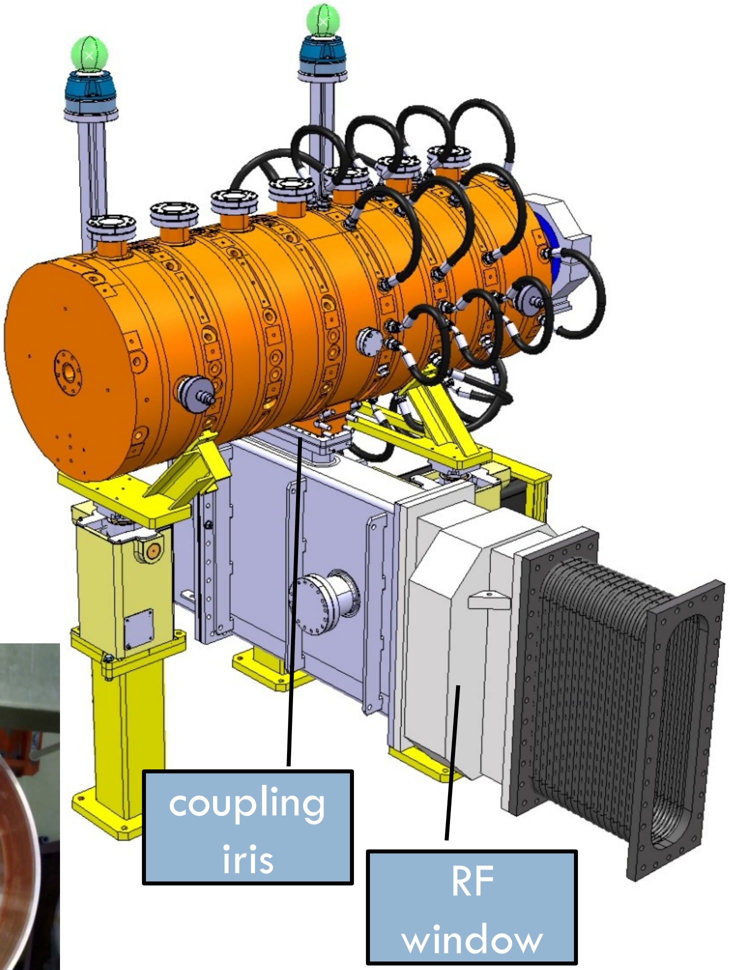


Accelerating structures - 2

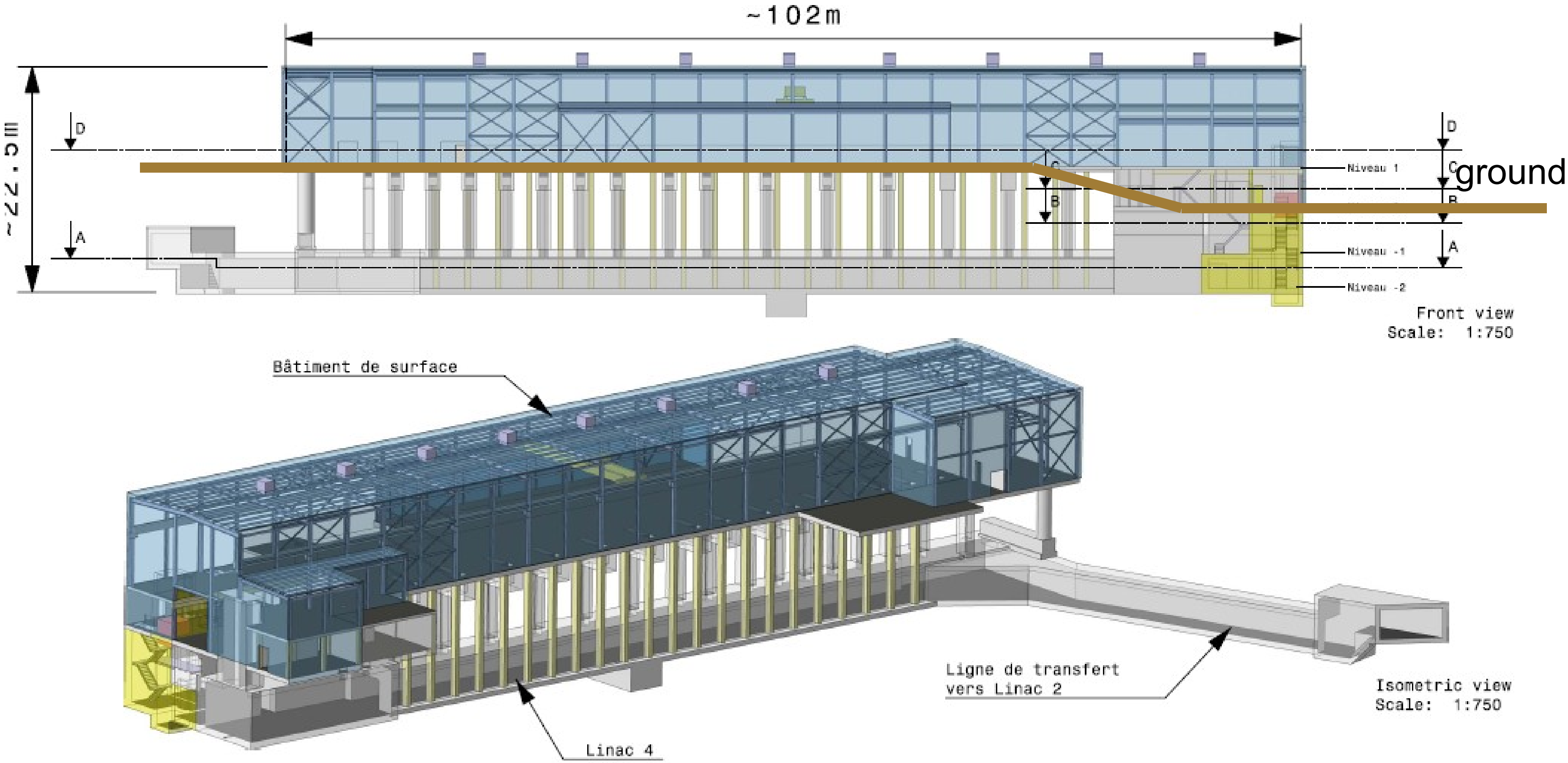
PIMS (Pi-Mode Structure)

- 100-160 MeV, 12 tanks of 7 cells each.
- An efficient way to avoid the CCL…
- Prototype fully tested.
- Focusing by external EMQs, tanks of 7 cells in pi-mode, coupling by 2 slots. Full-Cu elements, EB-welded.
- Construction started - collaboration Soltan (PL), FZ Julich (D), CERN.





Linac4 civil engineering



- Overall floor surface of Linac4 installations = 3’305 m2 over 4 levels.
- Machine tunnel 12 meters below klystron gallery level.
- Access module at the low energy side.

Building construction – 2008/10

Surface building, August 2010

Under the PSB technical gallery, May 2009

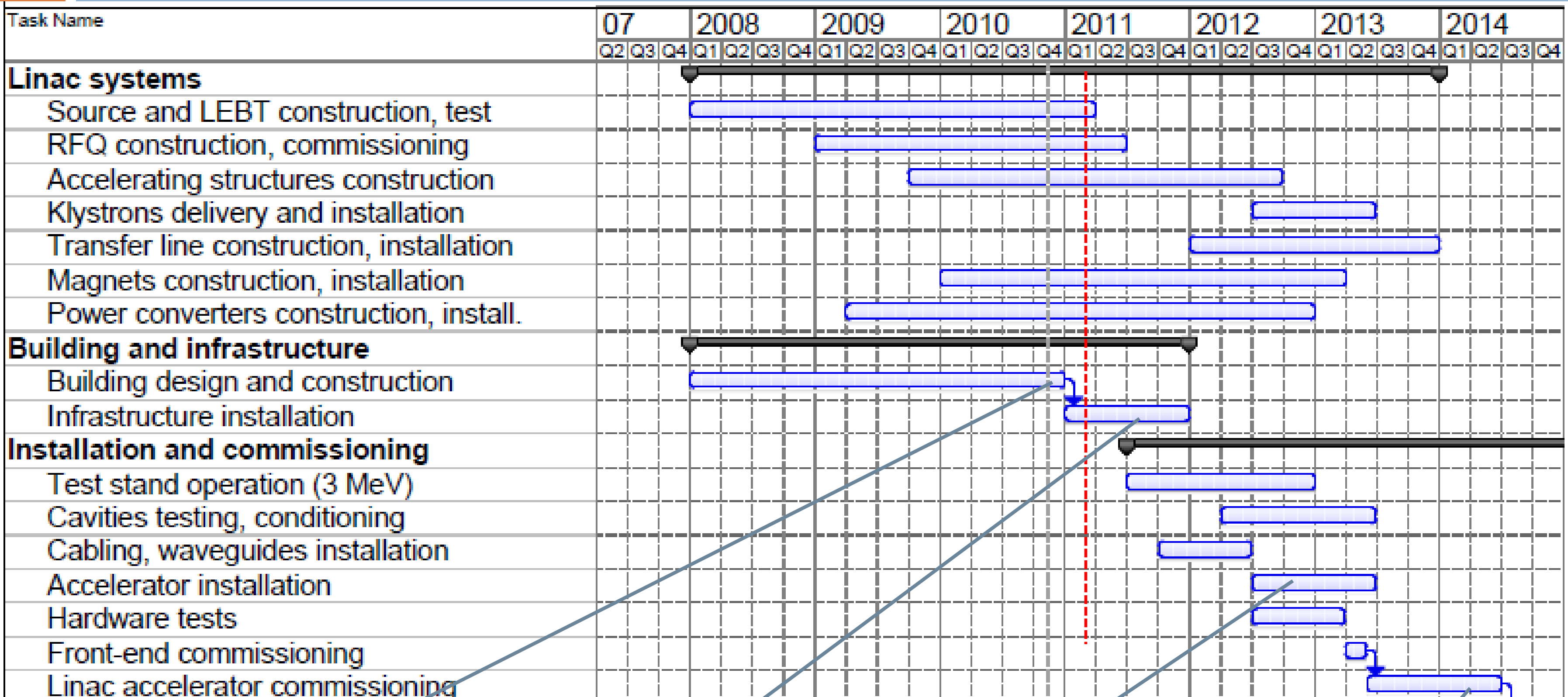
Excavation work, April 2009

Construction milestones

Start of building design	May 2007
Design frozen:	end 2007
Start of works:	20.10.2008
Building delivery:	29.10.2010

2011: installation of infrastructure (crane, lift, false floor, electrical and cooling networks, safety equipment, cabling, waveguides, ...).

Linac4 – schedule



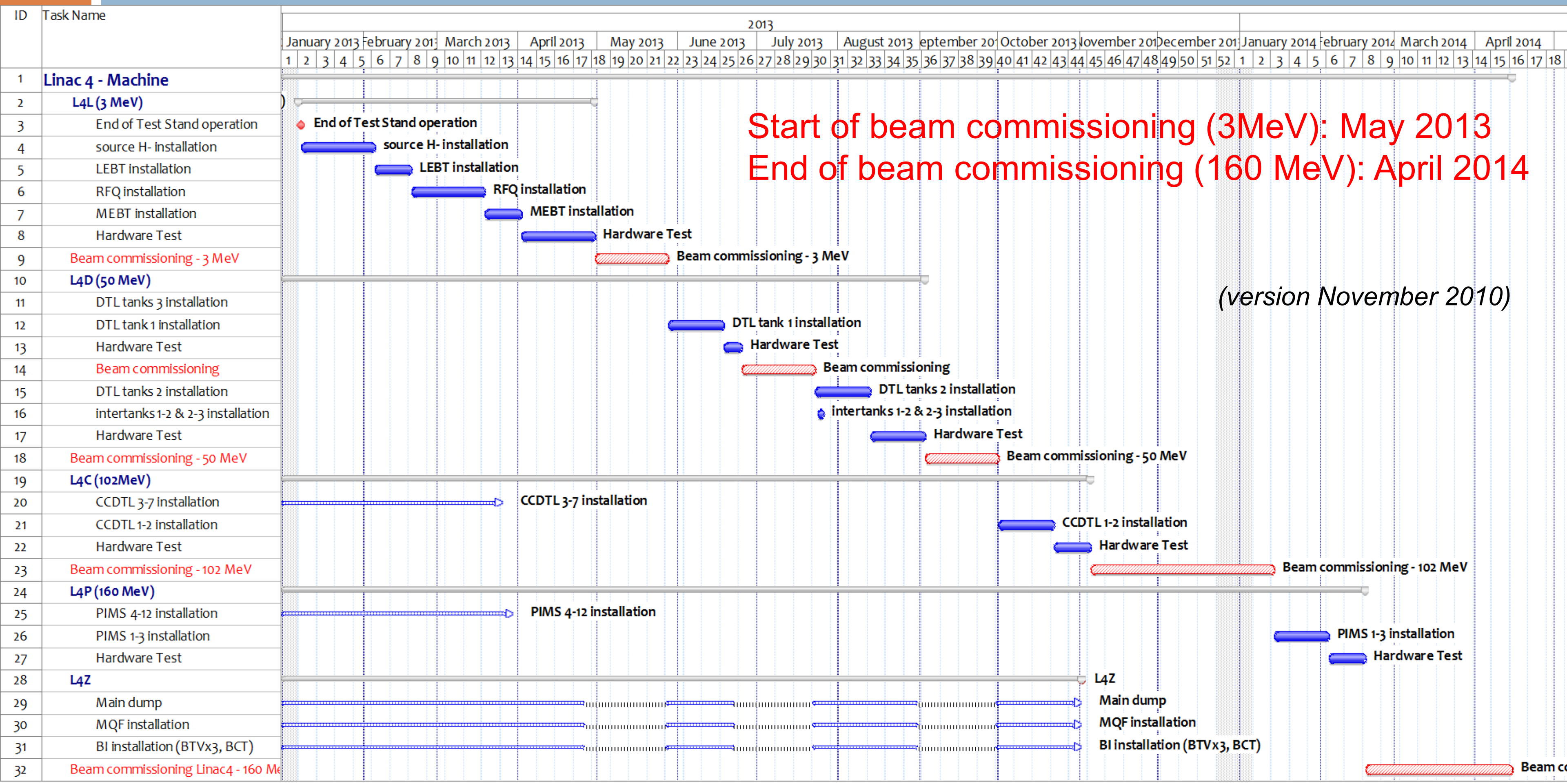
Building delivery

2011: Infrastructure installation

2012/13: Accelerator installation

2013/14: Commissioning

Linac4 commissioning schedule



5 commissioning stages:
(on intermediate dumps)

3 MeV ↔ 10 MeV ↔ 50 MeV ↔ 100 MeV ↔ 160 MeV

Connection to the PSB under discussion: in 2015 (1st long LHC shut-down) or later.

Linac4 project organization

LINAC4

- **1. Management**
  - 1.1 Management activities *M. Vretenar + core team, Deputies A. Lombardi, S. Maury*
    - 1.1.1 Collaborations – Russia, Poland, *T. Kurtyka, DG/PRJ*
    - 1.1.2 Collaborations – India, *V. Chohan, EN/MEF*
  - 1.2 Technical Coordination, *S. Weisz, DG/DI*
  - 1.3 Safety Coordination, *S. Maury, BE/ABP*
  - 1.4 Quality Assurance, *C. Rossi, S. Weisz*
  - 1.5 Design Office, *A. Dallocchio, BE/ABP*
  - 1.6 Radiation Protection, *J. Vollaire, DGS/RP*
  - 1.7 Reviews, webmaster, EDMS, *C. Noels, DG/DI*
- **2. Linac Systems**
  - 2.1 Ion Source and LEBT, *R. Scrivens, BE/ABP*
  - 2.2 Radio Frequency Quadrupole
    - 2.2.1 RFQ Funct. design, Commissioning, *C. Rossi, BE/RF*
    - 2.2.2 RFQ Mech. design, Fabrication, *S. Mathot, EN/MME*
  - 2.3 Chopper Line, *A. Lombardi, BE/ABP*
  - 2.4 Accelerating Structures, *F. Gerigk, BE/RF*
    - 2.4.1 Drift Tube Linac, *S. Ramberger, BE/RF*
    - 2.4.2 CCDTL and PIMS, *F. Gerigk, BE/RF*
  - 2.5 Linac Beam Dynamics, *A. Lombardi, BE/ABP*
  - 2.6 Radio Frequency Systems
    - 2.6.1 Low Level RF Systems, *P. Baudrenghien, BE/RF*
    - 2.6.2 High Power RF Systems, *O. Brunner, BE/RF*
    - 2.6.3 Slow Tuning and Interlocks, *L. Arnaudon, BE/RF*
    - 2.6.4 Buncher Amplifiers, *J. Broere, BE/RF*
  - 2.7 Beam Instrumentation, *U. Raich, BE/BI*
  - 2.8 Transfer Line, *C. Carli, BE/ABP*
  - 2.9 Magnets
    - 2.9.1 Magnet Design and Procurement, *T. Zickler, TE/MSC*
    - 2.9.2 Magnetic Measurements, *M. Buzio, TE/MSC*
  - 2.10 Power Converters, *D. Nisbet, TE/EPC*
  - 2.11 Vacuum Systems, *G. Vandoni, TE/VSC*
  - 2.12 Control Systems, *I. Kozsar, BE/CO*
  - 2.13 Beam Intercepting devices, *C. Maglioni, EN/STI*
  - 2.14 Machine Interlocks, *B. Puccio, TE/MPE*
  - 2.15 Intertanks, *J.B. Lallement, BE/ABP*
- **4. Installation Commiss.**
  - 4.1 Test Stand Operation, *C. Rossi, BE/RF*
  - 4.2 Transport, *C. Bertone, EN/HE*
  - 4.3 Survey, *M. Jones, BE/ABP*
  - 4.4 Linac Commissioning, *A. Lombardi, BE/ABP*
  - 4.6 Installation Coordination, *K. Foraz, EN/MEF*
- **5. Building, Infrastructure**
  - 5.1 Building Design, Construction, *L.A. Lopez, GS/SEM*
  - 5.2 Cooling and Ventilation, *Y. Body, EN/CV*
  - 5.3 Electrical Systems, *N. Dos Santos, EN/EL*
  - 5.4 Access Systems, *L. Hammouti, GS/ASE*

LINAC4 WBS 03-2011

Linac4 project composed by **37** Workpackages.

"Matrix" system: Groups and Departments allocate manpower to the WPs and define the priorities bw. projects.

Budget and schedule for each Workpackage are followed by an Earned Value Management (EVM) system.

The Linac4 Ion Source programme

- (slow) start back in **2002** trying to develop an ECR source for H-.
- Linac4 parameters frozen in 2004 and decision to speed up the source activities; after analysis of different design, decision in **2005** to build a source based on the DESY design (Cs free, antenna out of vacuum for higher reliability) with an improved RF generator (100 kW) to provide higher current.
- the programme starts in January **2006** with the goal to complete the source by **2007**; the need to completely redesign the DESY source and the lack of adequate manpower resources slow down the process.
- Mid-2007 Linac4 is approved; goal was to have source ready for tests in **2008**.
- Source started in **June 2009;** extensively tested at 35 kV between August 2009 - April 2010.
- Start to increase voltage towards 45 kV in **May 2010** but impossible to operate (flashovers). Different trials until August 2010.
- From **July 2010**, start definition of a crash programme to provide a source in time for the 3 MeV test stand and the Linac4 start-up. First problem is to find additional resources (manpower and budget).
- **June 2011**: resources, programme, design and schedule defined. Submit to international review committee.

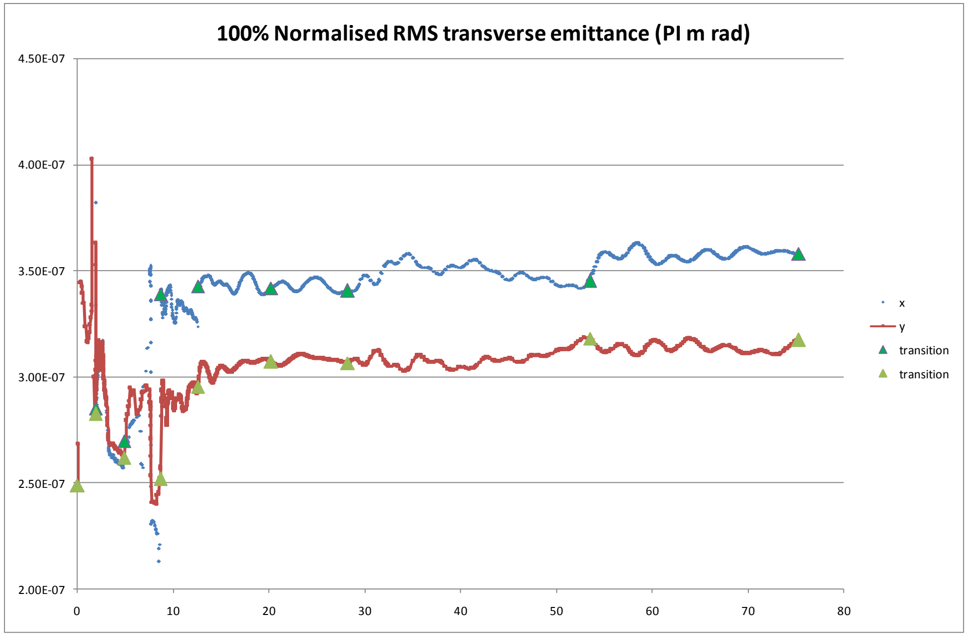
Requirements for Linac4 current

	PSB out (ppp)	PSB in (ppp)	Linac4 current in 400μs (mA)	Linac4 current in 160μs (mA)	Linac4 current in 80μs (mA)
LHC present	$0.7x10^{13}$	$0.9x10^{13}$	(3.6)	9	**18**
ISOLDE present	$3.5x10^{13}$	$4.5x10^{13}$	**18**	-	-
LHC final	$1.4x10^{13}$	$1.8x10^{13}$	(7.2)	**18**	**36**
ISOLDE final	$7.0x10^{13}$	$9.0x10^{13}$	**36**	-	-
		with 20% margin for beam loss		40 turns / PSB ring	20 turns / PSB ring

1. *Linac4 design 400 μs pulse and 40 mA current correspond to 10^{14} ppp (twice present ISOLDE with some additional margin).*
2. *After connection of Linac4 to the PSB, Linac4+PSB is required to provide the present nominal beams. It is expected to reach the goal for LHC 1-2 years after connection; there are no clear commitments to ISOLDE.*
3. *In order to gain some more margin, the maximum Linac4 pulse has been recently extended to 600 μs.*

- With linac current **20 mA** → present beams in PSB + full intensity LHC beam with 40 turns injection.
- With linac current **40 mA** → maximum ISOLDE beam + full intensity LHC beam with 20 turns injection.

Requirements for Linac4 emittance



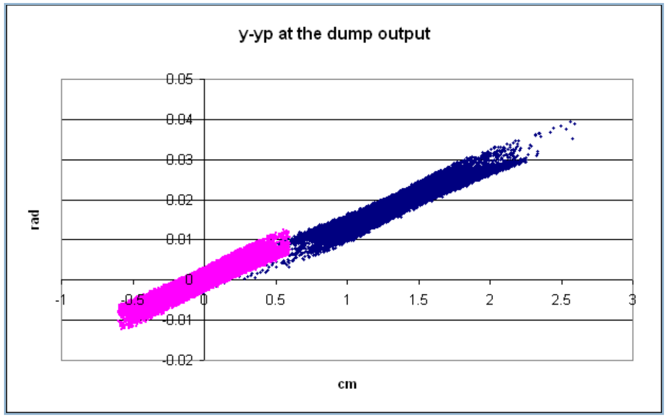
- Design transverse emittance from ion source 0.25 π mm mrad (rms)

- Design transverse emittance at PSB input 0.4 π mm mrad (rms)

If we have to compromise between current and emittance, what are our margins?

Maximum acceptances (no errors, zero current)

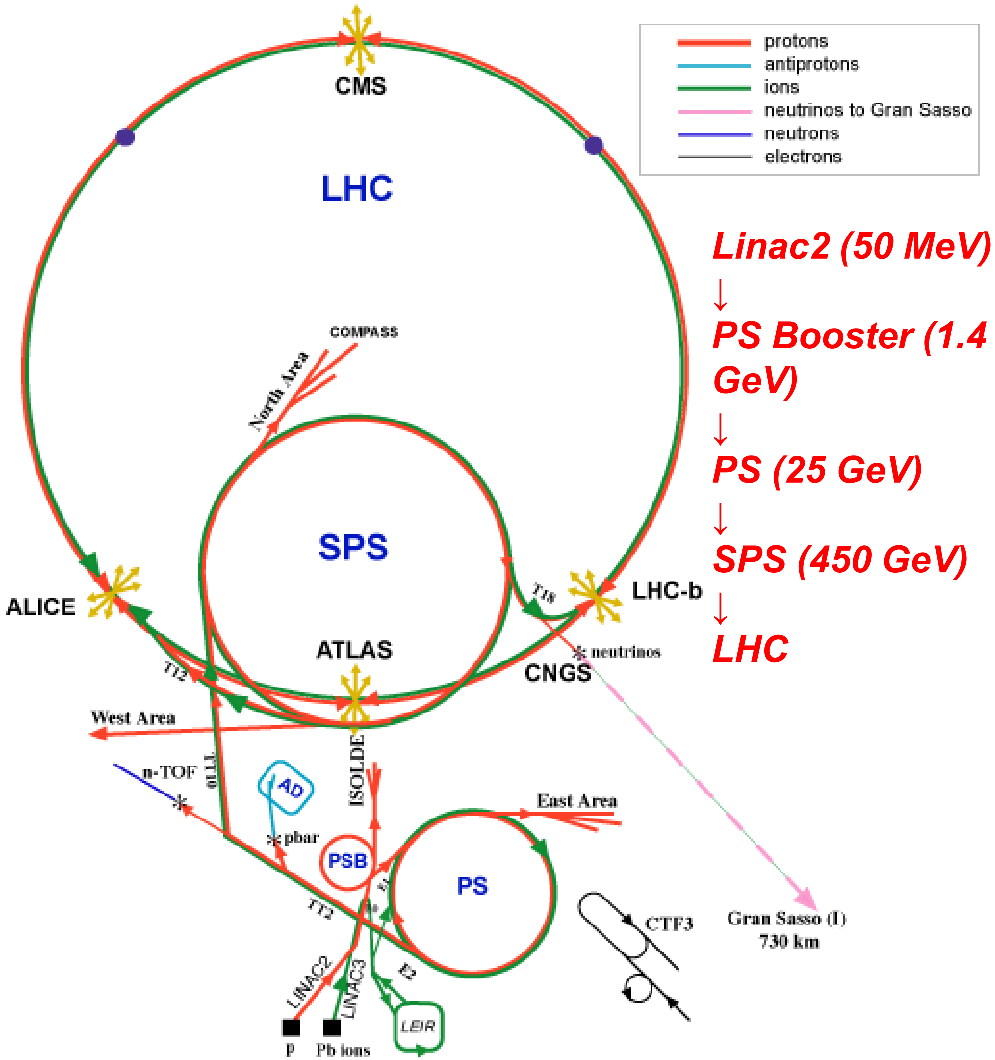
RFQ : 0.55 π mm mrad
Chopper : 0.4 π mm mrad
DTL : 0.8 π mm mrad
(comparable for other accelerating structures, larger for the transfer line)
The PSB can accept a somehow larger emittance



We probably have a (small) safety margin until reaching the RFQ acceptance limit, but the limitation in the chopper line can lead to more particles in the "empty buckets".

The end (for the moment),
More slides if needed!

Beam brightness and space charge



Linac2 (50 MeV)
↓
PS Booster (1.4 GeV)
↓
PS (25 GeV)
↓
SPS (450 GeV)
↓
LHC

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot \frac{R}{\beta\gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{X,Y}$: normalized transverse emittances

R : mean radius of the accelerator

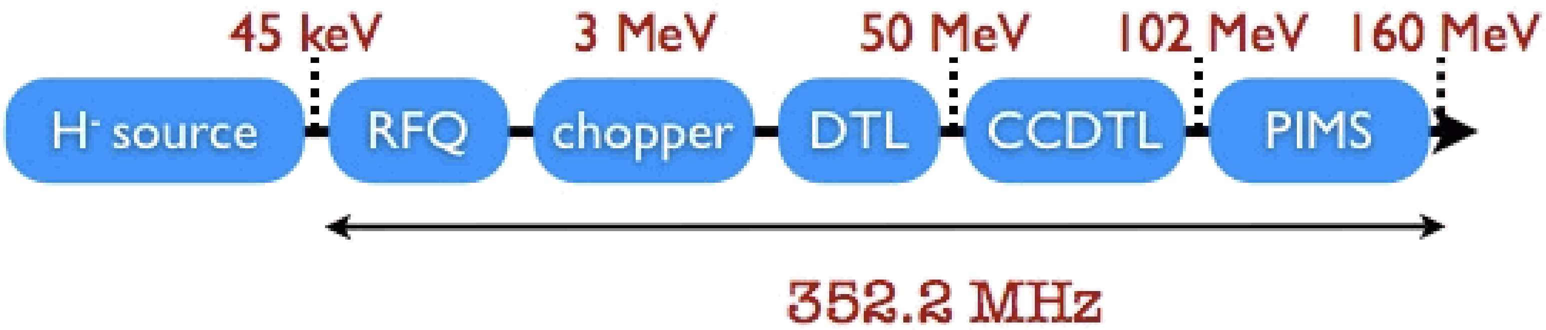
$\beta\gamma$: classical relativistic parameters

LHC Injection chain: 4 accelerators

Tune shift from space charge (coulomb repulsion) is the main factor limiting brightness (and intensity) in a (circular) accelerator .

Highest tune shift at injection → The only cure against space charge is to go up in energy at injection (tune shift proportional to $\beta\gamma^2$).

Linac4 architecture



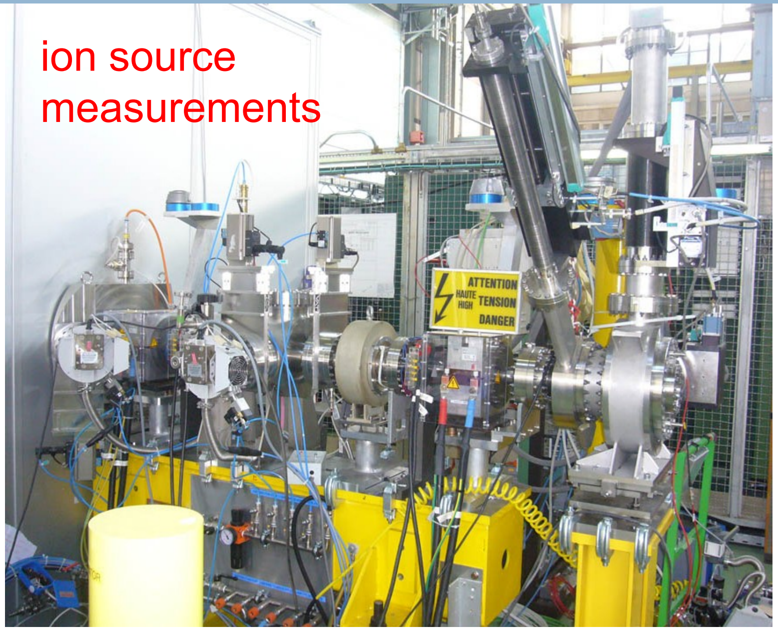
- No superconductivity (not economically justified in this range of beta's and for our low duty cycle)
- Single RF frequency of 352 MHz (no sections at 704 MHz, standardised RF allows for considerable cost savings)
- H- for injection in the PS Booster, chopping to minimize capture loss.
- High efficiency,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

Groundbreaking – 16.10.08

Groundbreaking (and start of civil engineering works) 16.10.2008
1 year 4 months after approval of the project

Status of Linac4 components

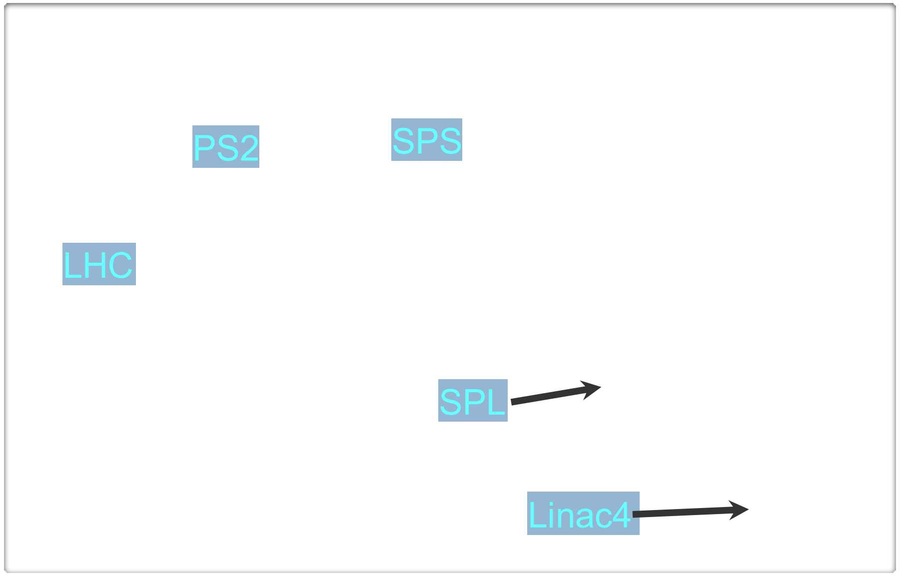
- **Ion source**: present source converted to protons, tested, will be used on test stand to commission the RFQ. Design of new source started, main components ordered, first tests expected for September 2012. International review of source programme 7-8.6.11.
- **RFQ**: 2/3 segments completed, 3rd being prepared for brazing (#1 June, #2 July). RF tuning foreseen in September/October, RF conditioning Nov./Dec.
- **DTL**: Drift tubes and tanks in production, Tank1 expected to be assembled end 2011.
- **CCDTL**: in construction in Russia, modules 1 and 2 (/7) ready in August 2011.
- **PIMS**: production started in Poland.
- **Klystrons**: first prototype (from Thales) expected at end 2011.
- **Modulators**: see Francis' presentation.
- **Quadrupoles**: PMQs for DTL1 received and tested, for DTL2 and 3 ordered; call for tenders out for EMQs.



ion source measurements

DTL tank1 (before finishing and plating)

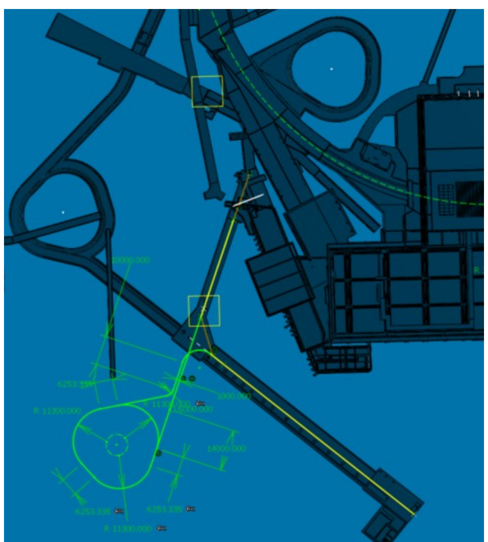
Options for the injectors upgrade



A new linac (Linac4) is the first and essential element for an upgrade of the LHC luminosity.

But what after Linac4 ?

2 options have been compared, and a 3rd one is being analyzed.

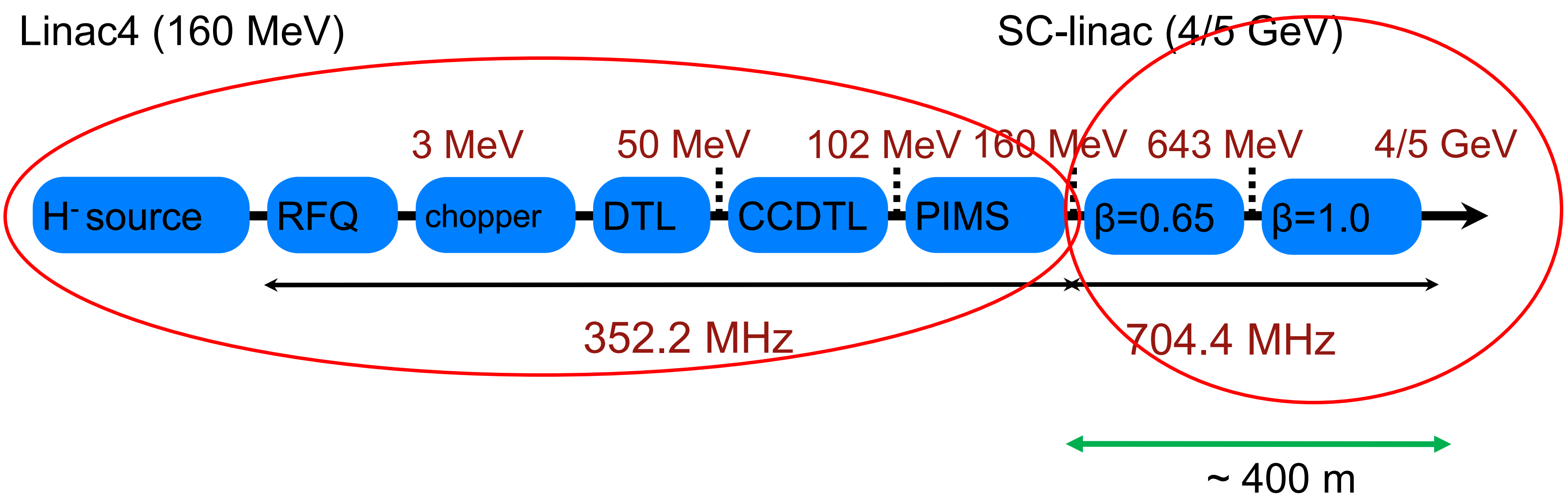


1. Old program (2008-09): a) replace the PSB with a high-energy linac (SPL=Superconducting Proton Linac, 4 GeV); b) replace the PS with a new PS2; c) upgrade the SPS. *Expensive, high potential for luminosity (but SPS bottleneck), can be upgraded to high-intensity.*
2. New program (2010): a) upgrade of PSB final energy to 2 GeV (possible with present magnets); b) consolidation of PS; c) upgrade (coating, new RF) of SPS. *Lower potential luminosity increase, but less expensive and achievable in a shorter time.*
3. Alternative intermediate option (being analyzed now): replace the PSB with a Rapid Cycling Synchrotron (RCS) at 2 GeV.

Linac4 for the SPL

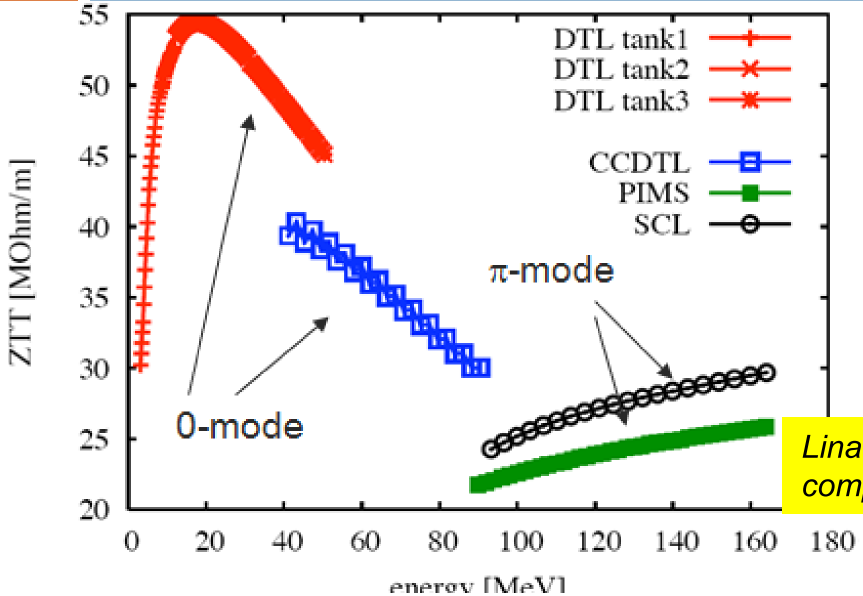
Superconducting Proton Linac (SPL) study in progress at CERN extension of Linac4 to 4 or 5 GeV and upgrade to 6% duty cycle

Project in the same category as Project-X at FNAL, high-intensity driver for neutrinos (Superbeam, Neutrino Factory) and/or Radioactive Ion Beams

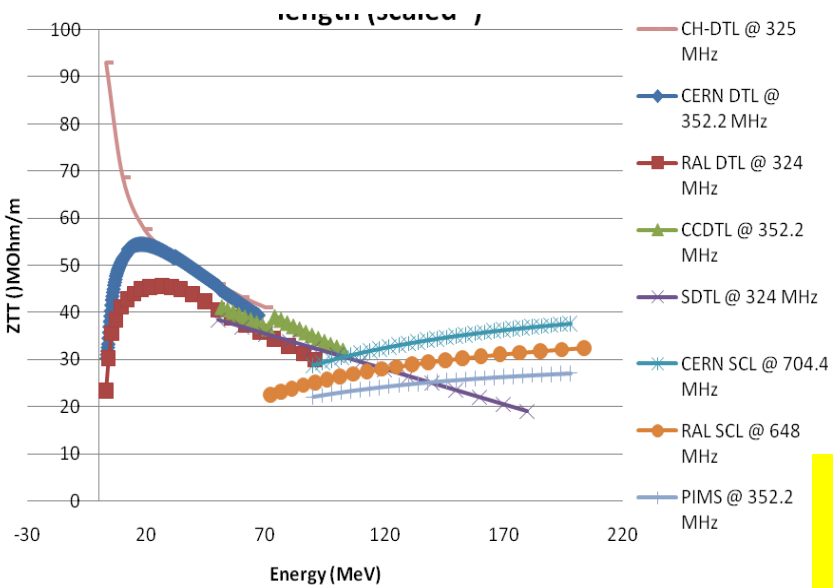


R&D for SPL is progressing (construction and test of a 4-cavity cryomodule)
Synergy with ESS !

Linac4 shunt impedances



Linac4 comparison



General comparison done by the "HIPPI" Joint Research Activity (2008)

Effective shunt impedance (linac definition, MΩ/m) along Linac4.

Included a 20% reduction from computed Q-value (surface roughness, tuners, etc.).

1. Efficiency of 0-mode (Alvarez DTL, CCDTL decreases rapidly with energy.
2. At 100-120 MeV, can pass to a π-mode structure (shunt impedance increasing with energy).
3. Theoretical efficiency of 352 MHz pi-mode is about 20% lower than 704 MHz pi-mode (difference down to ~10% taking into account surface roughness) → does not justify the higher cost of 704 MHz.

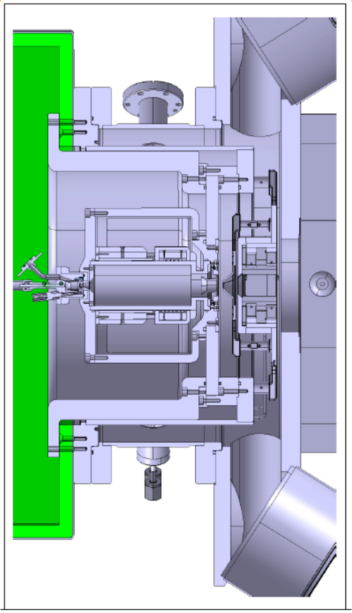
Completing the infrastructure

Linac4 – virtual tour

Linac4
Virtual Tour

JP.Corso EN-MEF - CERN

The H- source



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

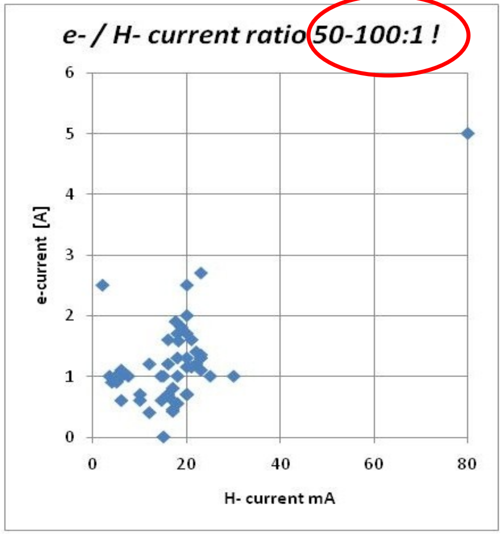
Improved RF generator (100 kW) and matching network for higher current, extraction at 45 kV (at DESY 35 kV with 30 kW RF was giving 30 mA).

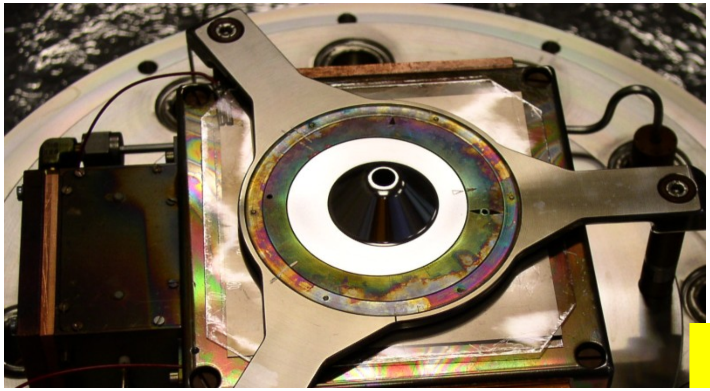
So far, could not operate at 45 kV (and 20-30 mA extracted at 35 kV).

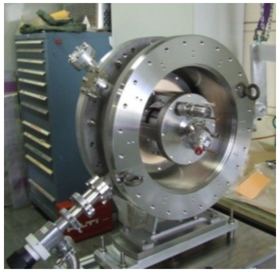
Reason: intense electron production, which melts the e^- dump. Vaporization (and destruction) of the dump induces sparks preventing the source operation.

Strategy:

a. use the present source with protons for commissioning the RFQ.
b. build another source, of the RF type (same generator) but Cesiated.

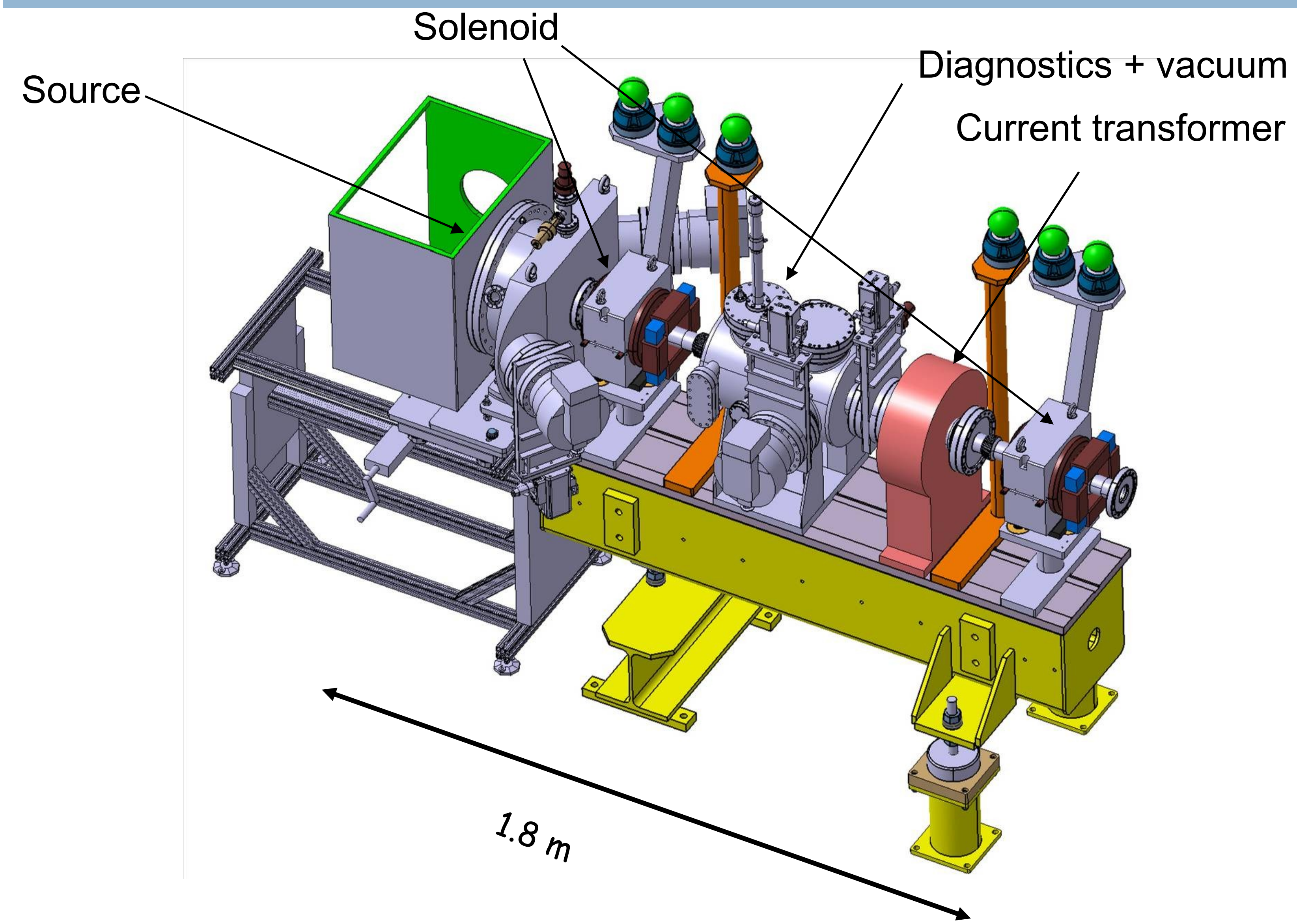




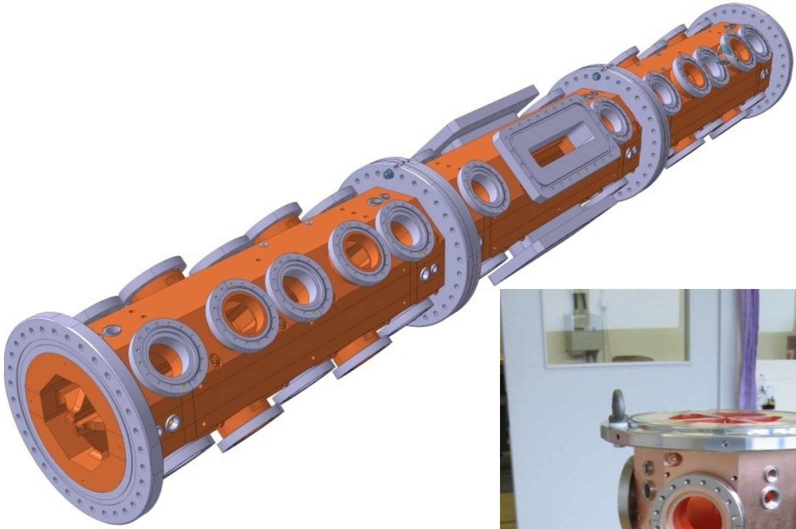


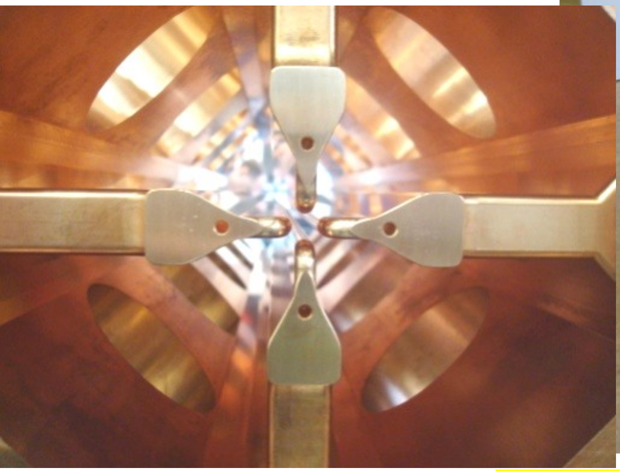
extraction electrode

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).

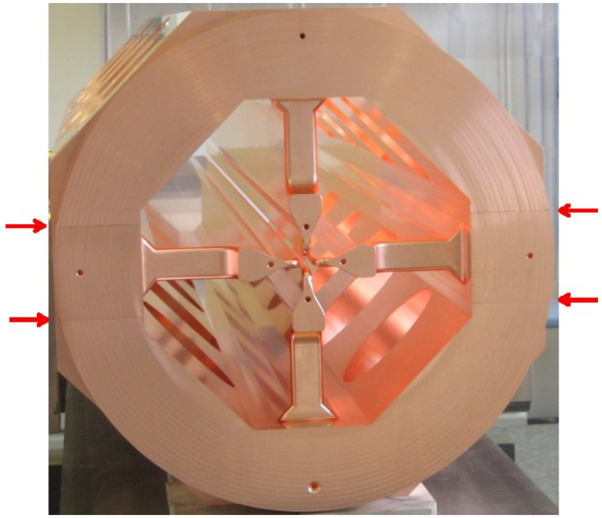
Collaboration with CEA Saclay (in charge of thermal simulations and of RF design, measurement and tuning).

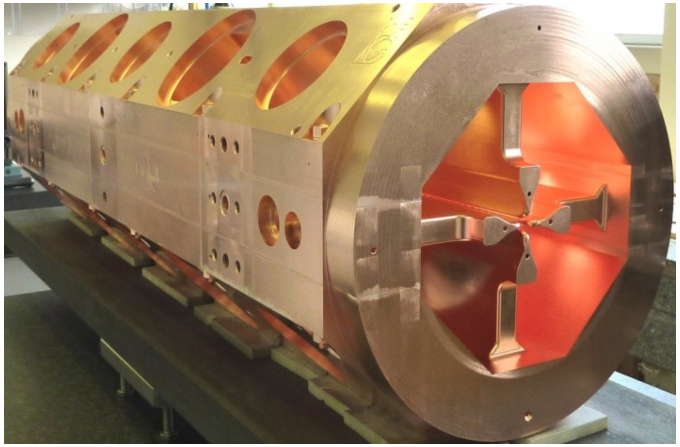
Construction entirely done at CERN: machining, metrology, brazing (horizontal).

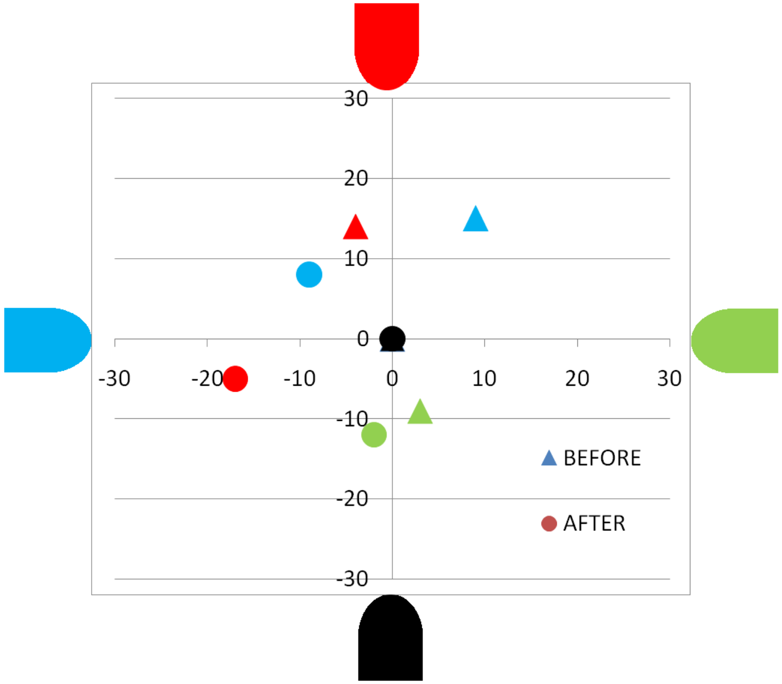
Status: Modules #1 and #2 completed (2 brazing steps), Module #3 under final machining.

Goal: RFQ ready for beam tests end 2011.

Brazing of the 1st RFQ Module





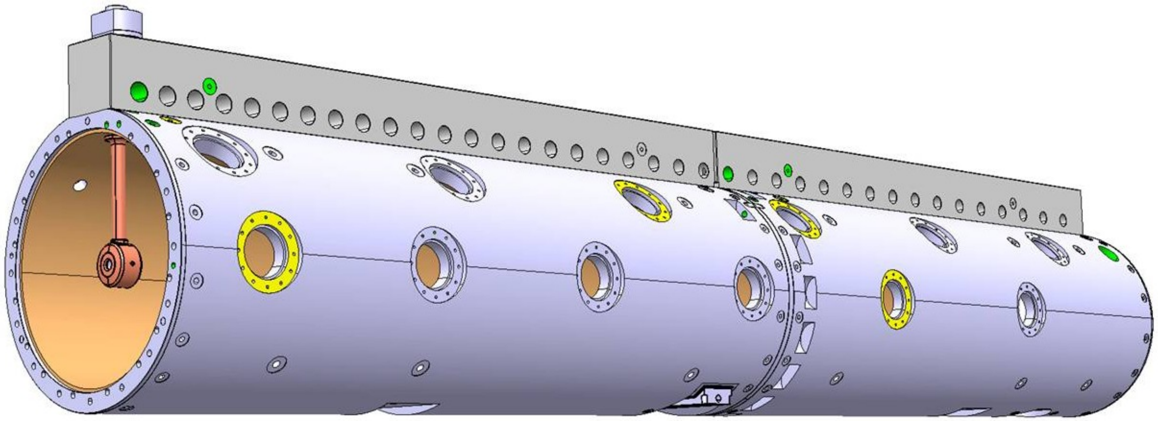


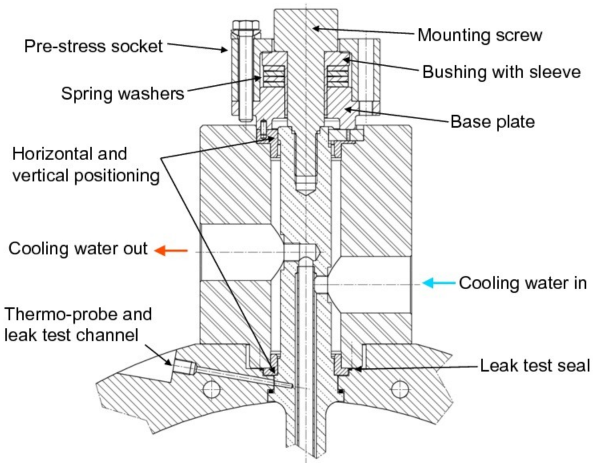
Deformations <25 μm (tolerance 30 μm).

Linac4 – Drift Tube Linac

DTL (Drift Tube Linac)

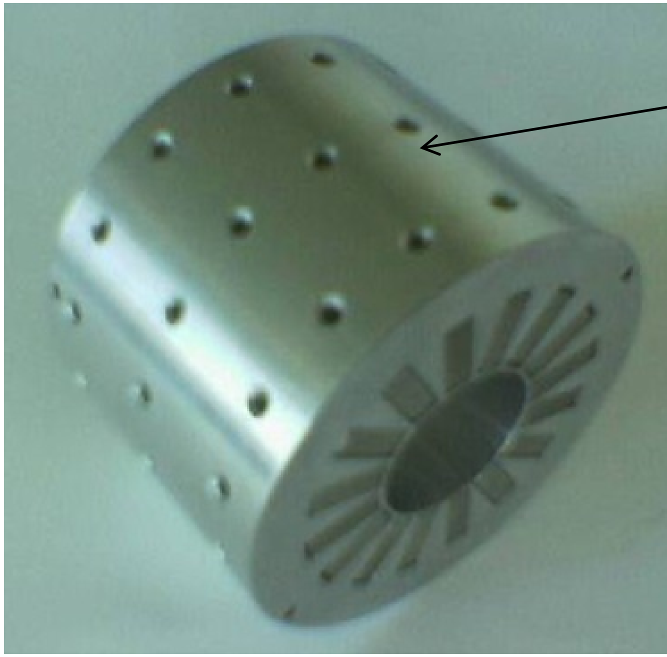
- 3-50 MeV, 3 tanks.
- Permanent Magnet Quadrupoles in vacuum.
- New design for DTs mounting mechanism (no bellow or O-rings).
- Prototype (1m, 12 drift tubes) fully tested.
- Construction started (DTs with ESS-Bilbao).
- Tank1 ready for test at end 2011.





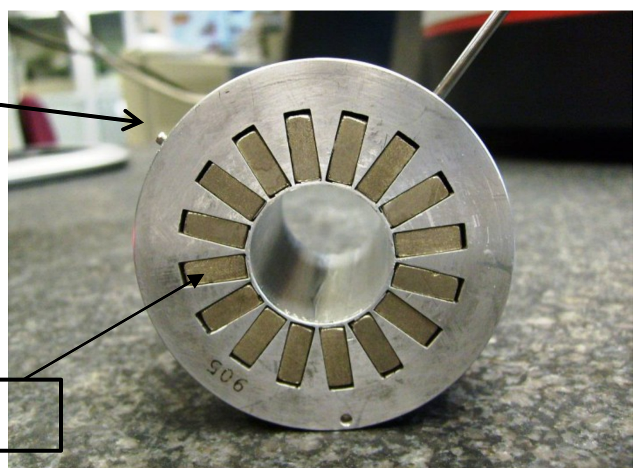
Important improvements with respect to present DTL linacs

PMQs for the DTL



48 screws

Hole and Pin to position in drift tube

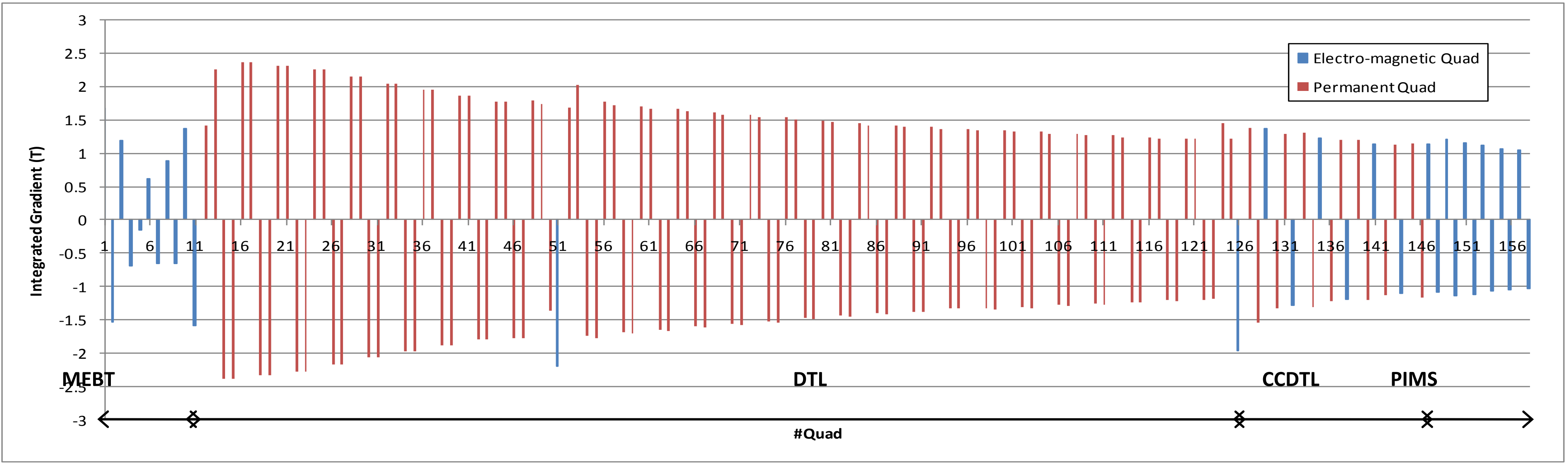


16 pole pieces

- **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

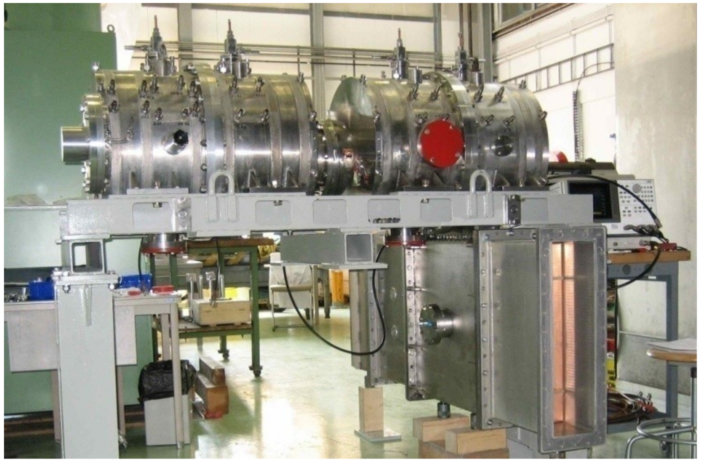
- Majority of focusing elements are permanent quadrupoles (136 PMQ and 31 EMQs in the linac).
- 3 families
  - 45 mm long , 22/60 inner/outer diametre in to be housed in drift tubes oftank1
  - 80 mm long , 22/60 inner/outer diametre to be housed in drift tubes tank2and3
  - 100mm long 45/124 inner/outer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

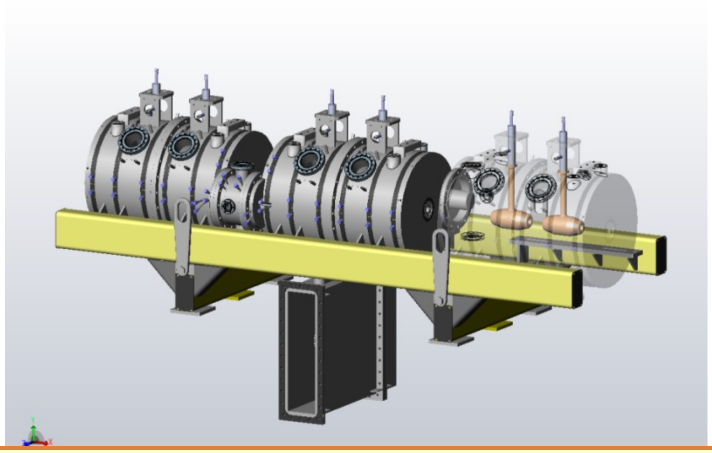


Integrated Gradient of the quadrupoles along linac4

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 and #2 completed, under low-power tests at BINP. To be delivered to CERN for testing in 2011.

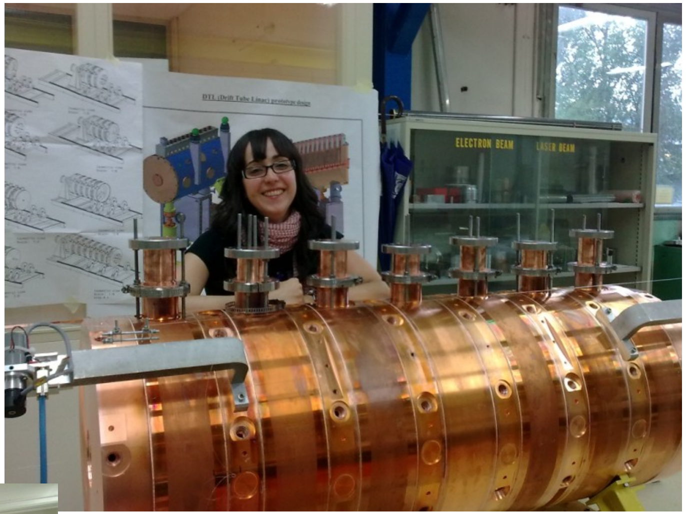


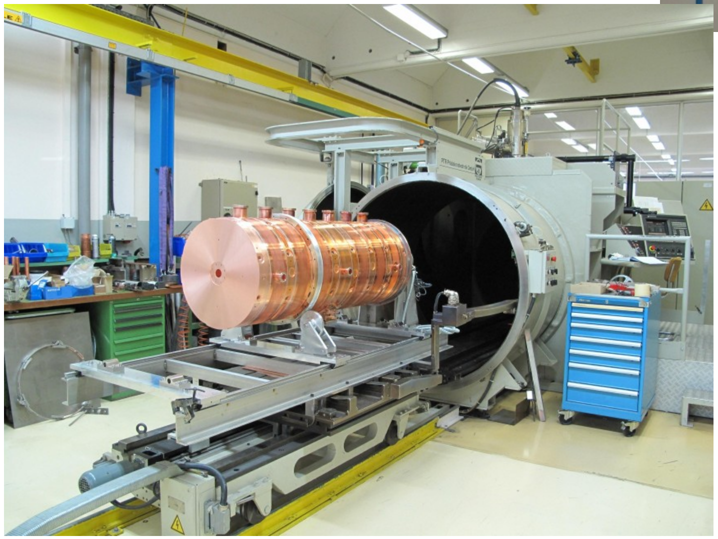


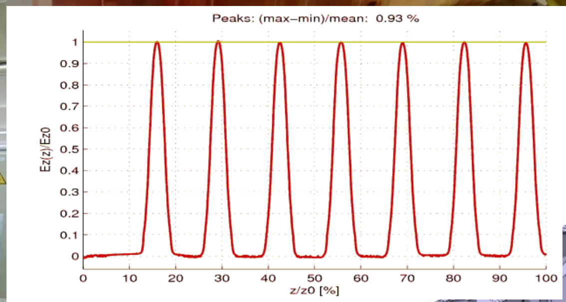
Structure used for the first time in a particle accelerator

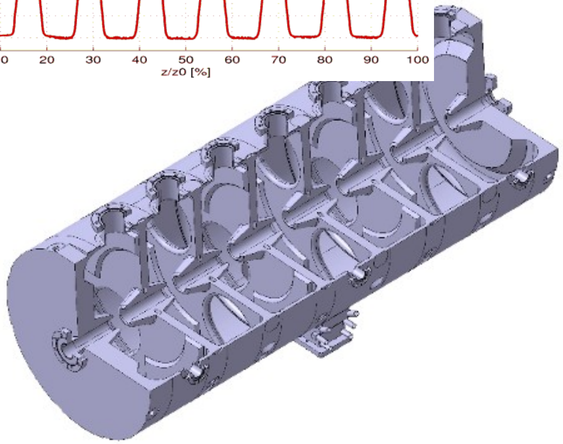
Linac4 – Pi-Mode Structure

- 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 started (2011) in collaboration with Soltan Institute (Warsaw) and FZ Julich.





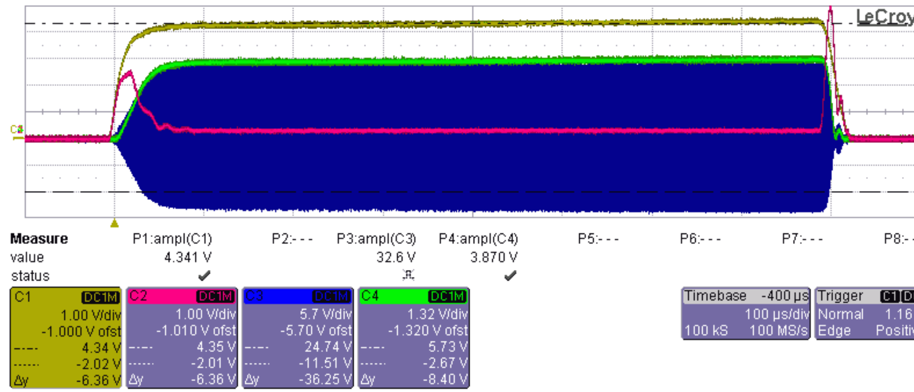


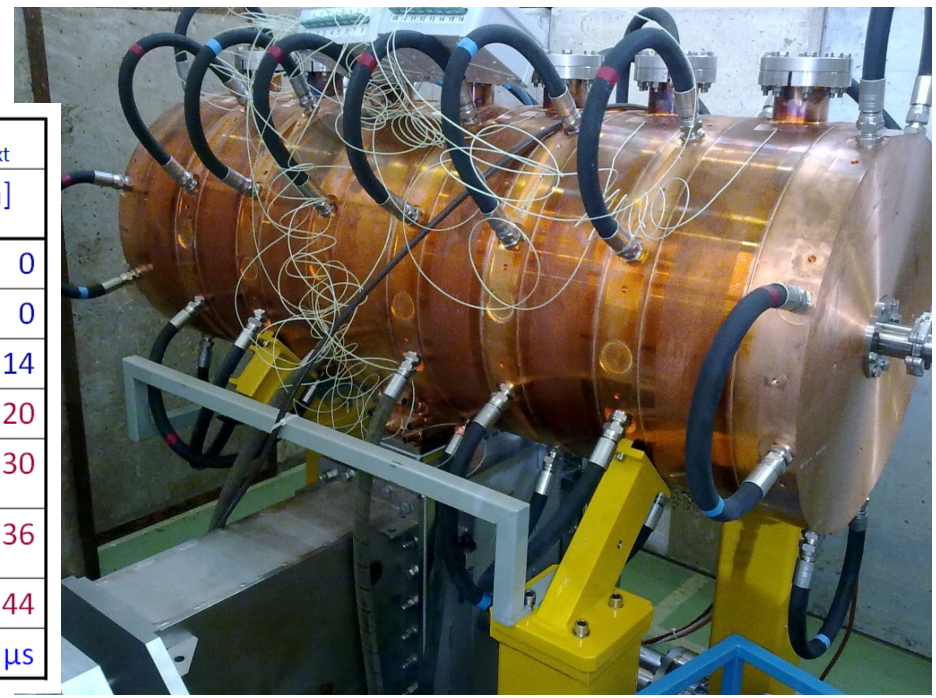


Structure used for the first time in a proton accelerator

PIMS high-power conditioning

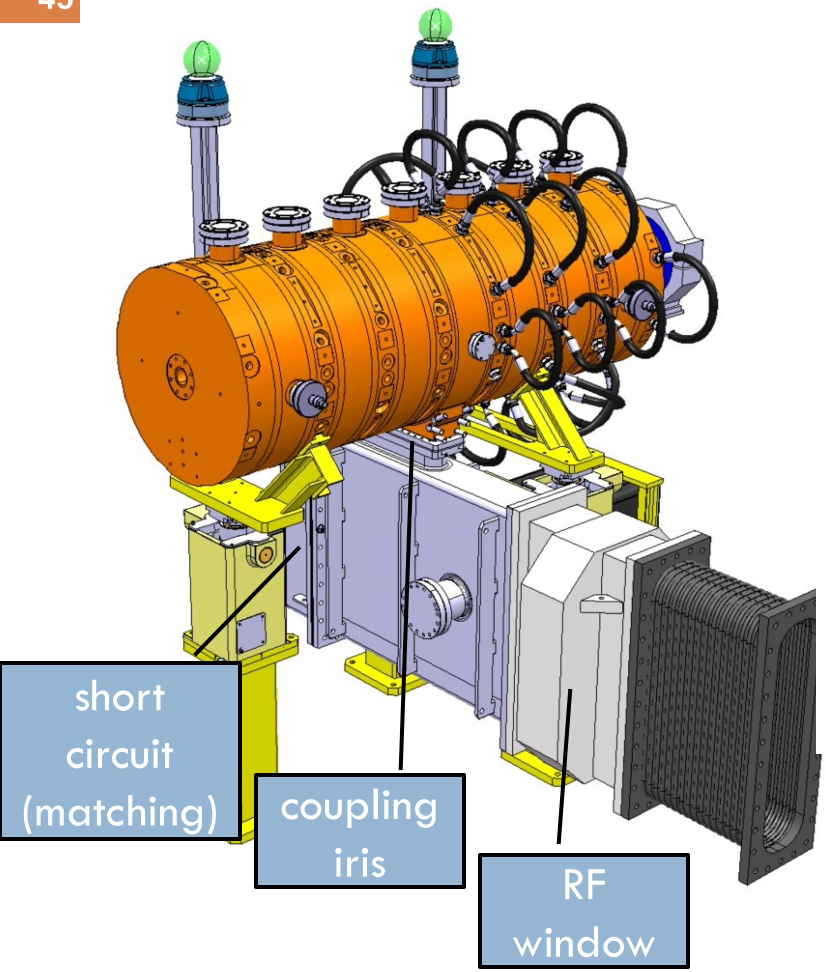
- cavity #1, length 1.4 m, weight ~700 kg
- ZT^2: 26.5 MΩ/m (95% of HFSS calculation)
- cell to cell coupling k: 5.6% to 4.8%
- $E_{S,max}$ = 1.8 Kilpatrick (33.2 MV/m @ 352MHz)

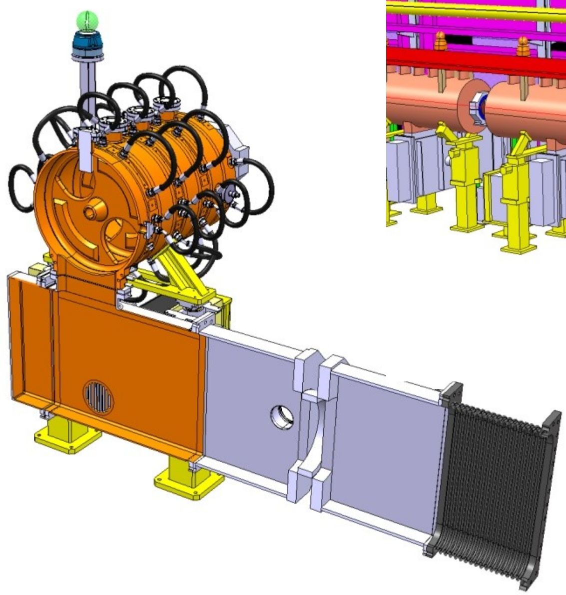


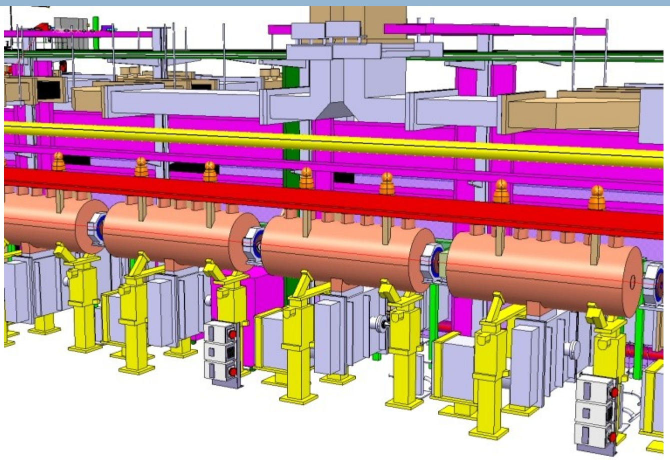


day 2010	T_{RF} [h]	com.	P_{peak}	T_{pulse} [µs]	vacuum [mbar]	X-ray $_{axis}$ [mSv/h]	X-ray$_{ext}$ [µSv/h]
2.11.	2	setup	1 kW	800	$5 \cdot 10^{-6}$	0	0
3.11.	6	multipactor	1 .. 10 kW	25	$8 \cdot 10^{-6}$	0	0
4.11.	6		700 kW	180	$8 \cdot 10^{-6}$	12	14
5.11.	2	modulator	700 kW	300	$4 \cdot 10^{-6}$	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





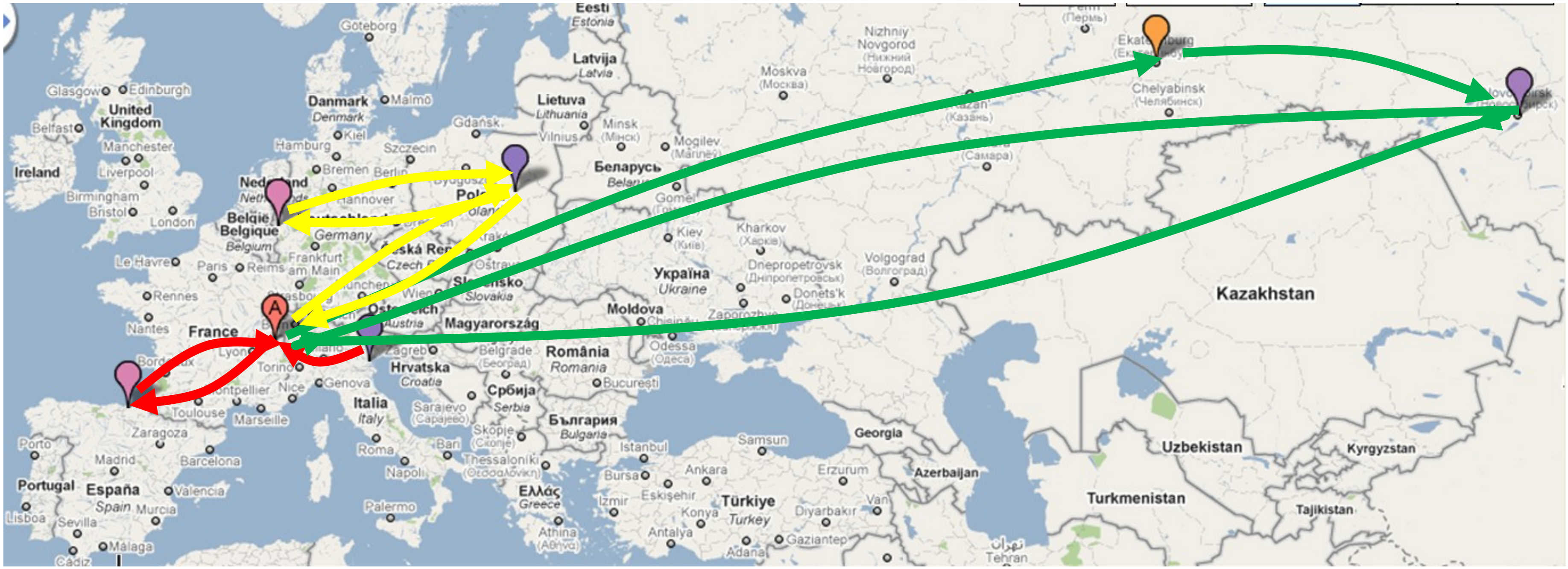


Coupling to a tangential waveguide closed by a short circuit at $\lambda/4$ from the iris

Simple, reliable, cheap

Accelerating structures construction

Construction of the Linac4 accelerating structure – an European enterprise (and beyond…)



Drift Tube Linac (DTL):
prototype from INFN/LNL (Italy), drift tubes from ESS-Bilbao (Spain), tanks and assembly at CERN

Cell-Coupled DTL:
tanks from VNIIEF (Snezinsk), drift tubes and assembling from BINP (Novosibirsk)

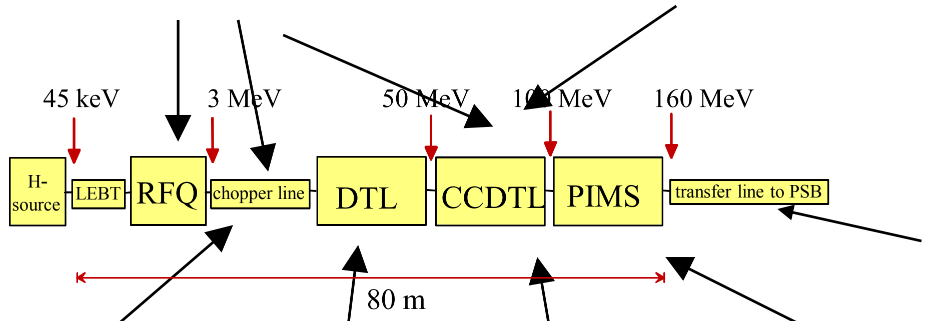
PI-Mode Structure (PIMS): tanks from Soltan Institute (Poland), EB welding from FZ Juelich (Germany), assembly and final EB welding at CERN.

Linac4 – External Contributions

Network of agreements to support Linac4 construction. Relatively small fraction of the overall budget, but access to specialized manpower and share of information with other teams. Integration at the component level.

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

Prototype modulator, waveguide couplers, alignment jacks from India, *started*



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

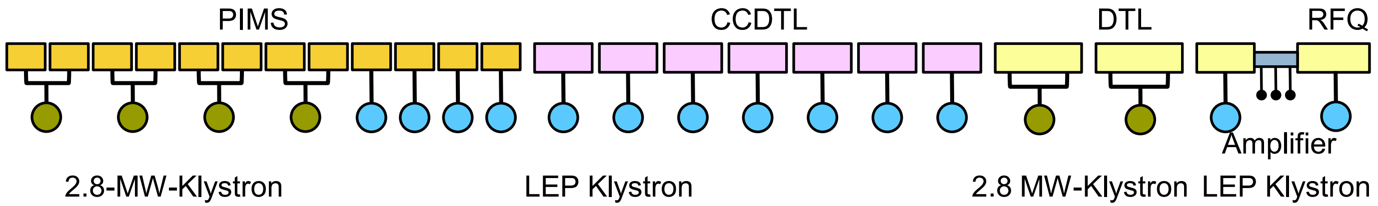
Chopper line built in a EU Joint Research Activity *completed*

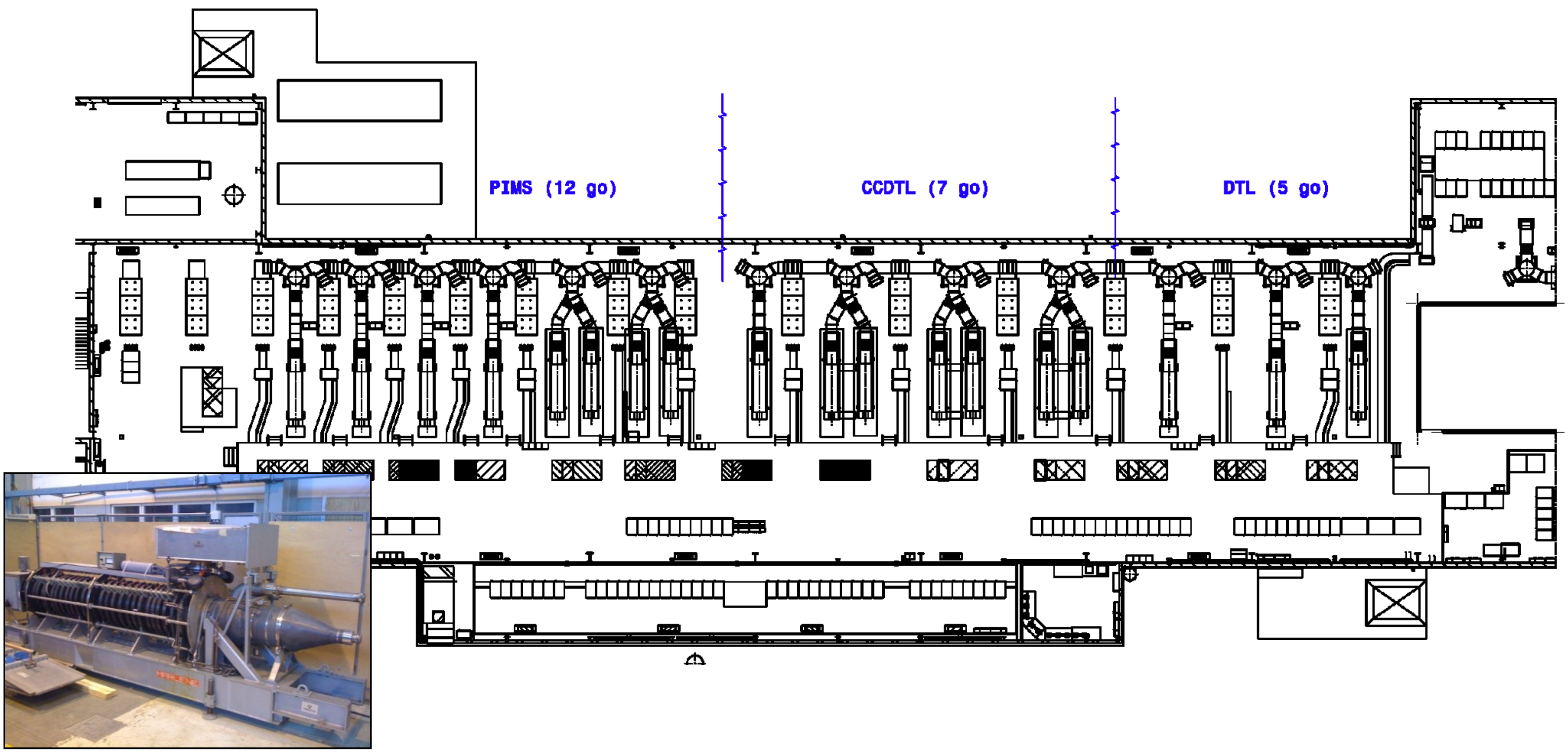
Participation of ESS-Bilbao in DTL construction, *started*

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

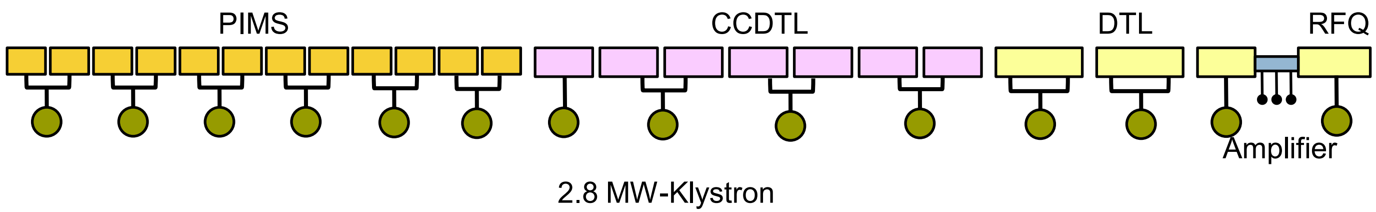
Collaboration agreement with Soltan Institute (Poland) for PIMS construction, *started*

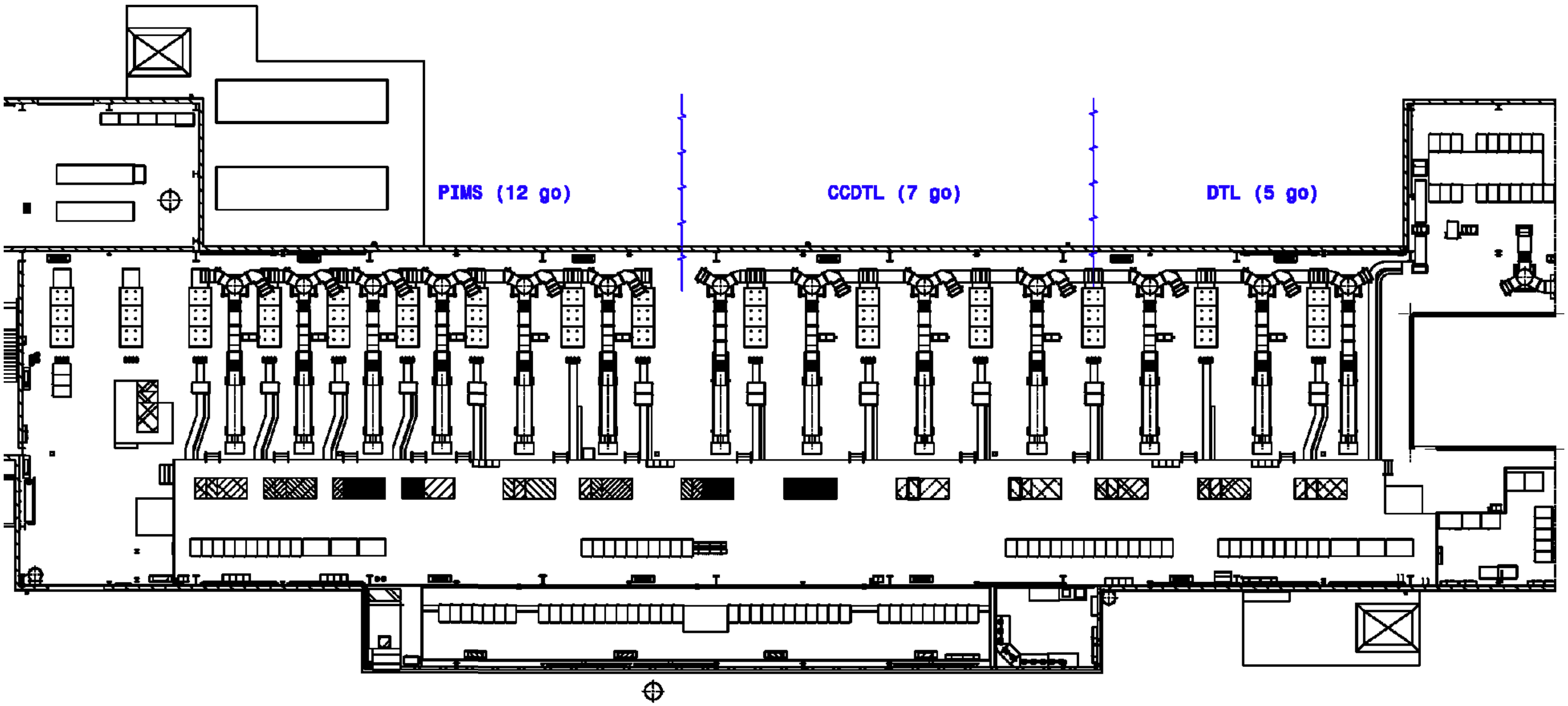
RF system initial: LEP klystrons





RF system final: new klystrons

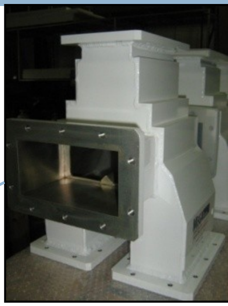


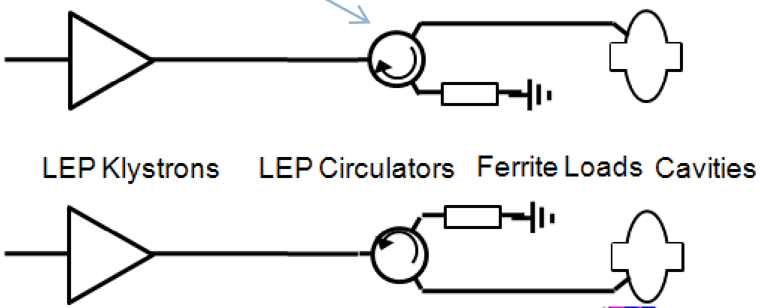


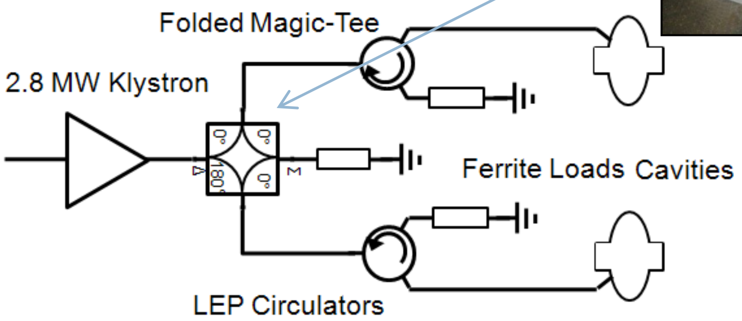
RF stations

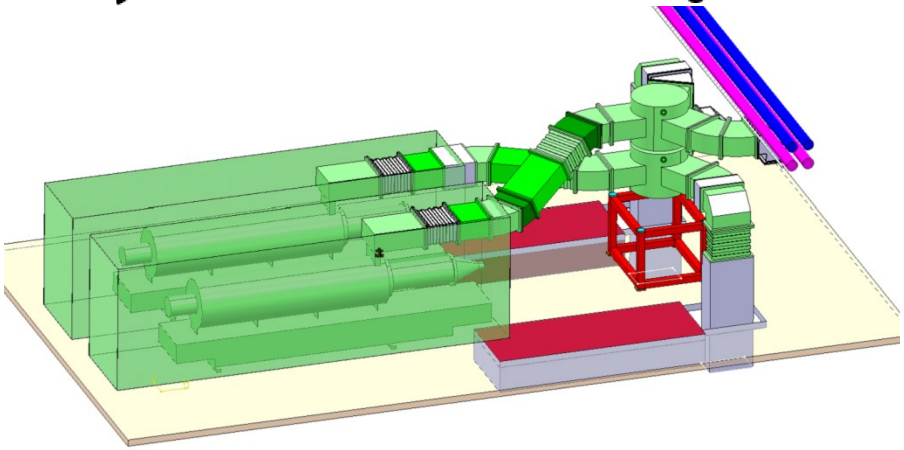
LEP klystrons (2 x 1.3 MW)

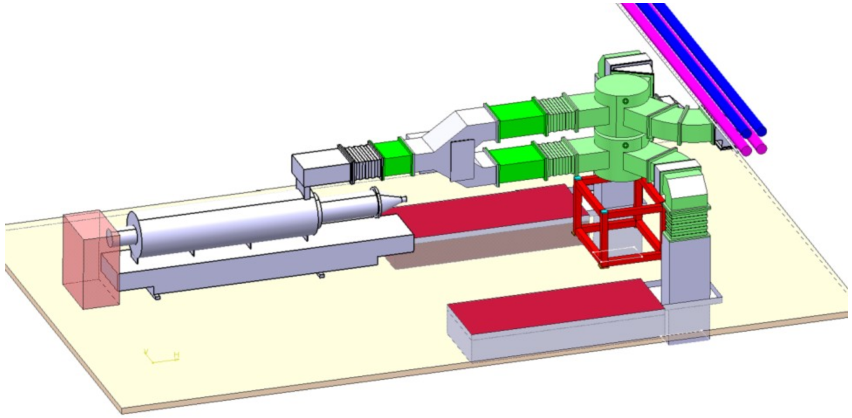
new klystrons (1 x 2.8 MW)





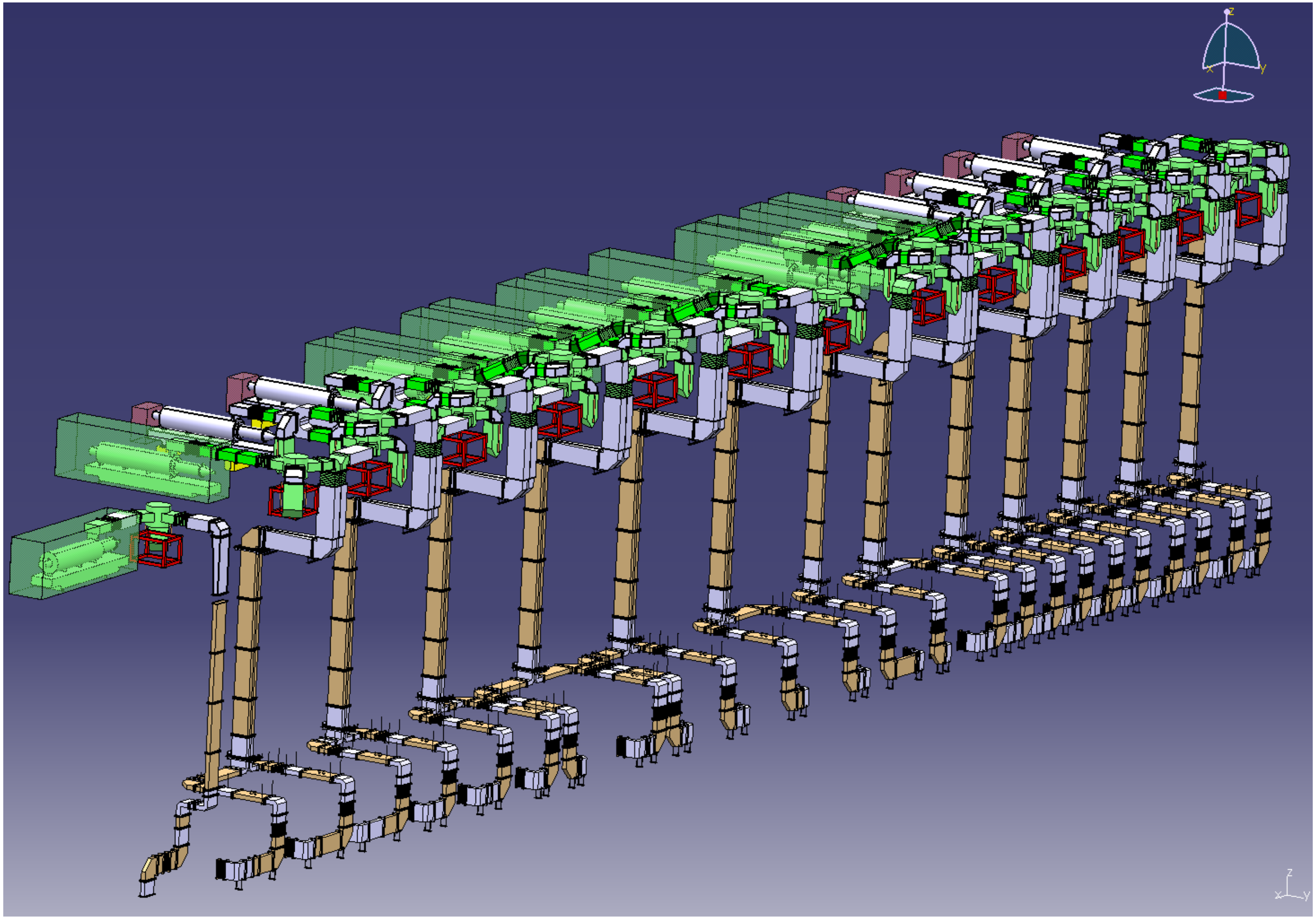






Order for 8 new klystrons placed, shared between Thales and CPI

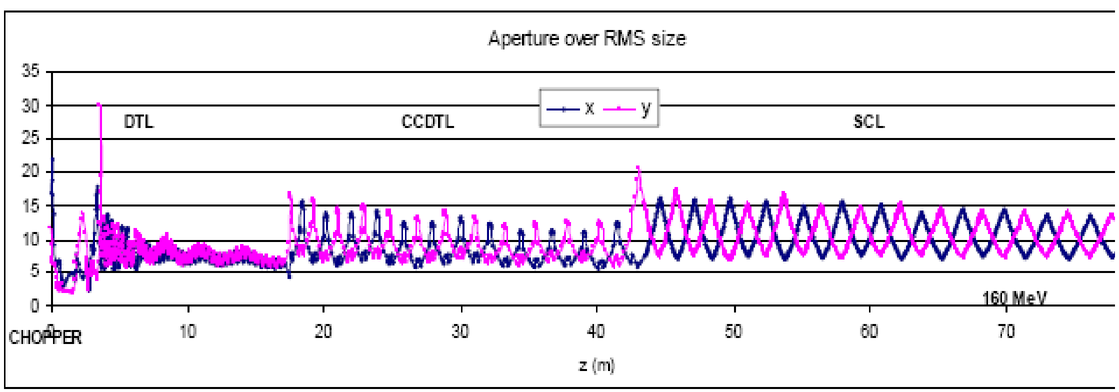
The RF System – overall view

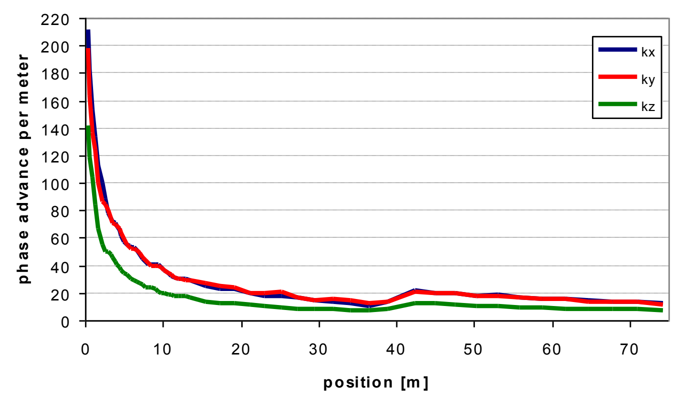


Linac4 – linac beam dynamics

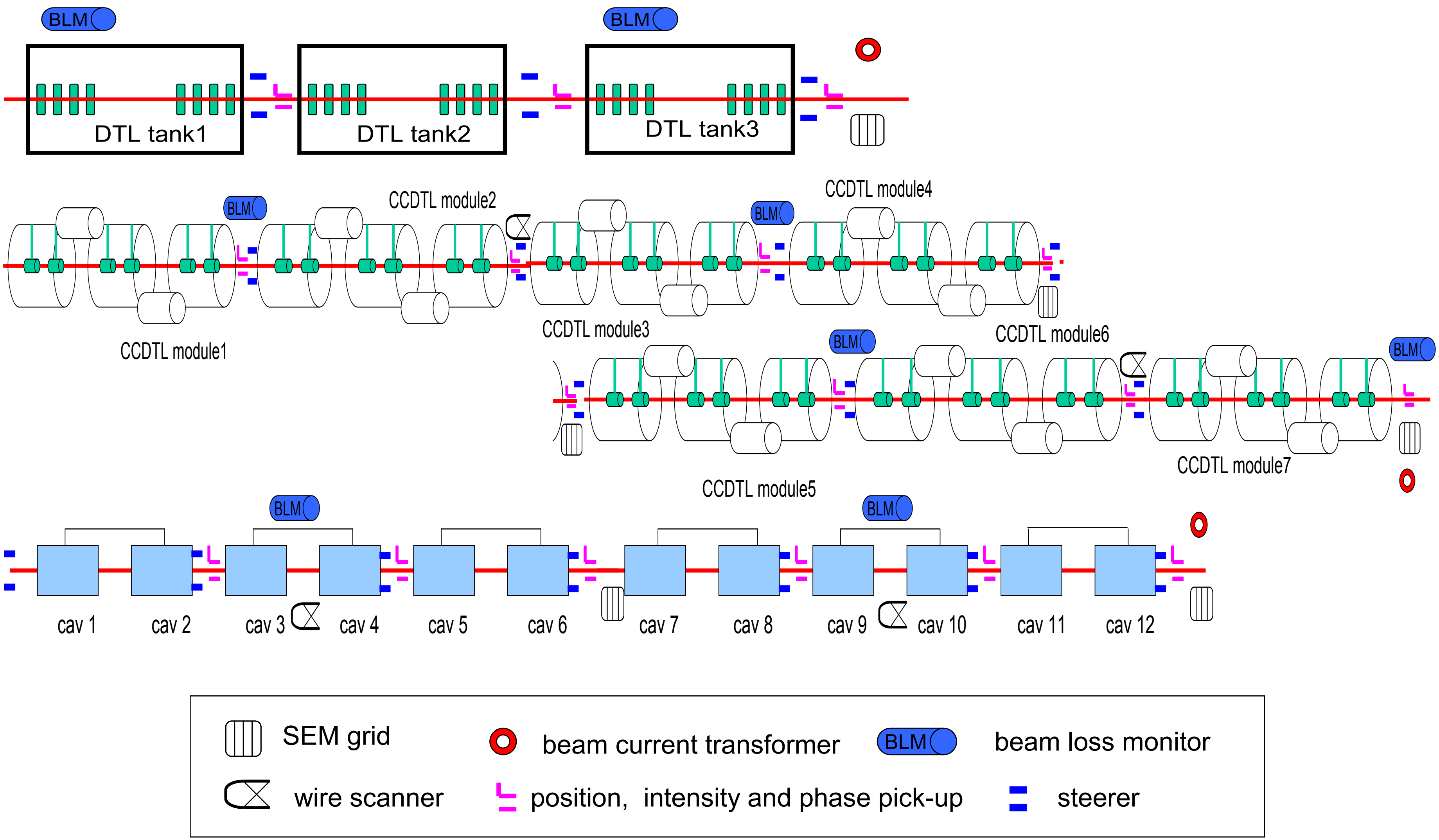
Beam optics design to minimize beam loss and emittance growth for:
1. Low activation (in particular for high duty cycle operation).
2. Minimum emittance growth for painting into the PSB acceptance.
3. Losses on concentrated spots (collimation).

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)





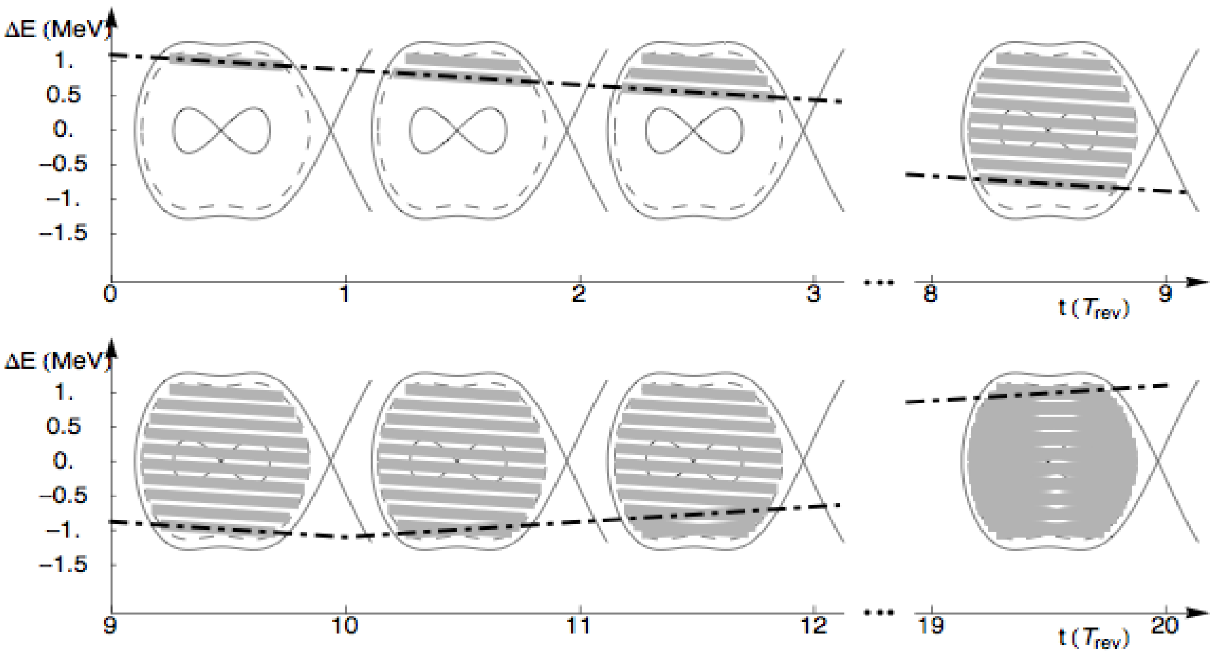
Diagnostics



Energy ramping of Linac4 beam

Optimization of bunching factor in the PS Booster:

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=0.12MeV
  - Already too high intensity for LHC with nominal 65mA peak current
  - Under discussion: minimum energy modulation period - how to use that in the Booster

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:

- Simple systems, with minimum number of components.
- Standardized equipment, with sufficient spares.
- 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.

Project Management Tools

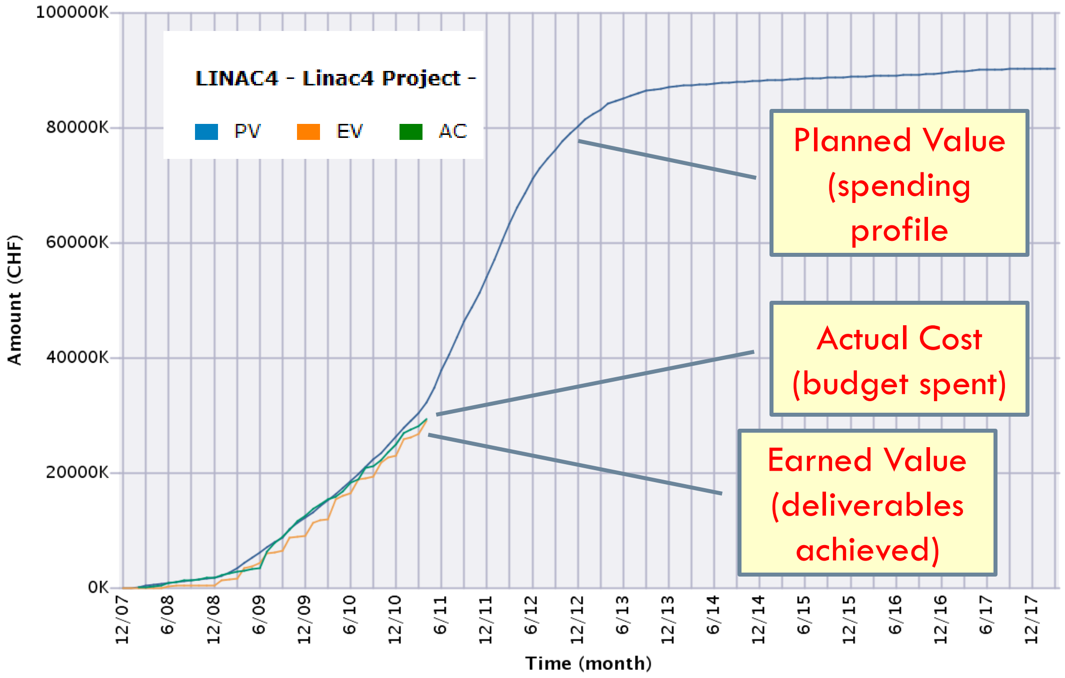
- After the difficult experience of the LHC construction (2 financial crisis, several coordination problems) it has been decided that Linac4 should be a pilot project in terms of modern management tools.
- However, we made an effort to adapt existing tools to an accelerator project and to keep a pragmatic approach… useful without introducing too much "reactive power"…

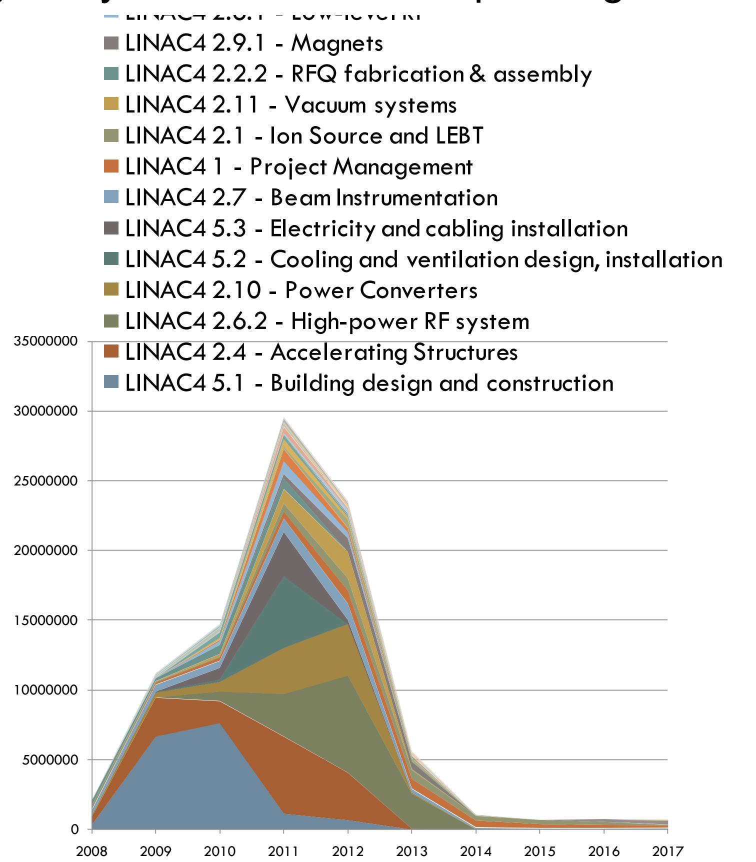
1. Quality Assurance Plan (light document, mainly a list of procedures).
2. Safety File (100 pages): global safety approach for the project, giving reference to the relevant safety documents. *Turned out to be very useful, simplified our life with respect to the safety authorities.*
3. Risk Analysis (subcontracted to Siemens AG, 1 week of seminars). *very useful for team construction, in the management of the resources and with respect to the top management.*
4. Earned Value Management tool to follow budget and progress *(next slide)*.

Earned Value Management

Budget and progress followed by an Earned Value Management (EVM) tool developed at CERN for LHC, improved for Linac4.

The different Workpackages in the project enter a workplan relating budget with deliverables. The software follows the progress, immediately showing delays and over/under spending.





Conclusions

- Linac4, to be completed by the end of 2014, will pave the way to the increase of the LHC luminosity. At the same time, it will replace Linac2 with a more modern and powerful machine and allow for high duty cycle operation for other applications.
- Civil engineering is completed, as well as the 3D full integration. Defined a construction strategy integrating industrial components and in-kind contributions. Construction of the main components is progressing.
- New designs and technologies have been developed for Linac4, aiming at efficiency, reliability, maintainability and low cost.
- The project is followed by modern project management tools, trying to minimize the overhead for the technical team.

Acknowledgements

This work is the result of the contribution of many different teams and persons. In particular, for the material of this talk I am grateful to:

Ion source: J. Lettry, R. Scrivens

RFQ: C. Rossi, S. Mathot, A. France (CEA), O. Piquet (CEA)

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DTL: S. Ramberger, P. Bourquin, Y. Cuvet

CCDTL: F. Gerigk, A. Tribendis (BINP)

PIMS: R. Wegner, F. Gerigk, G. Favre, A. Dallocchio

Beam dynamics: A. Lombardi, J.B. Lallement, G. Bellodi

RF: O. Brunner, N. Schwerg

PS Booster: C. Carli, K. Hanke, W. Weterings

Civil engineering and integration: L.A. Lopez-H., J.-P. Corso

Project organization, EVM: S. Weisz, J. De Jonghe, J. Coupard