Design, construction & commissioning of the Linac4 accelerating structures

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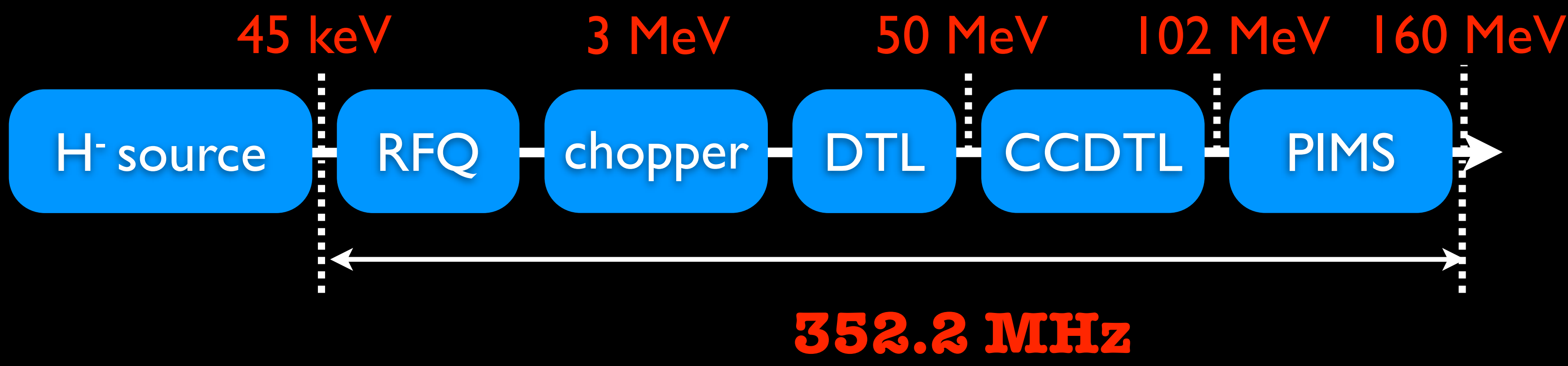
Overview

- highlights & status of RFQ, DTL, CCDTL & PIMS,
- lessons learned,
- installation/commissioning planning,



THPB010: M.Vretenar, "Progress in the construction of Linac4 at CERN"

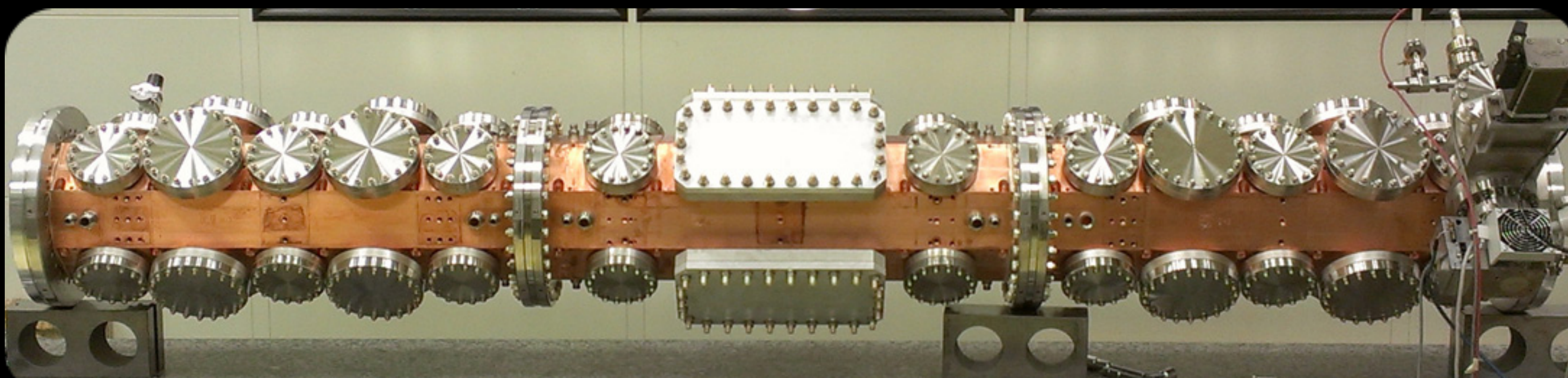
RFQ

(project eng: C. Rossi)

design (CEA/CERN) and construction (CERN): 2009 - 2012

Parameter	Value
frequency	352.2 MHz
length	3.06 m
vane voltage	78.27 kV
maximum aperture a	1.8 mm
maximum modulation	2.36
average aperture r_0	3.3 mm
ρ/r_0	0.85

Parameter	Value
min. longitudinal radius	9 mm
max field on pole tip	34 MV/m
Kilpatrick	1.84
focusing parameter	5.7
acceptance at I=0 mA	1.7 π mm mrad
final synchronous phase	-22 deg



THPB038: C. Rossi et al, "Assembly and RF tuning of the Linac4 RFQ at CERN"

The assembled RFQ is now installed at the 3 MeV Test Stand, where it is undergoing the accelerating field tuning (supported by CEA team). RF commissioning & beam tests before the end of 2012.

DTL

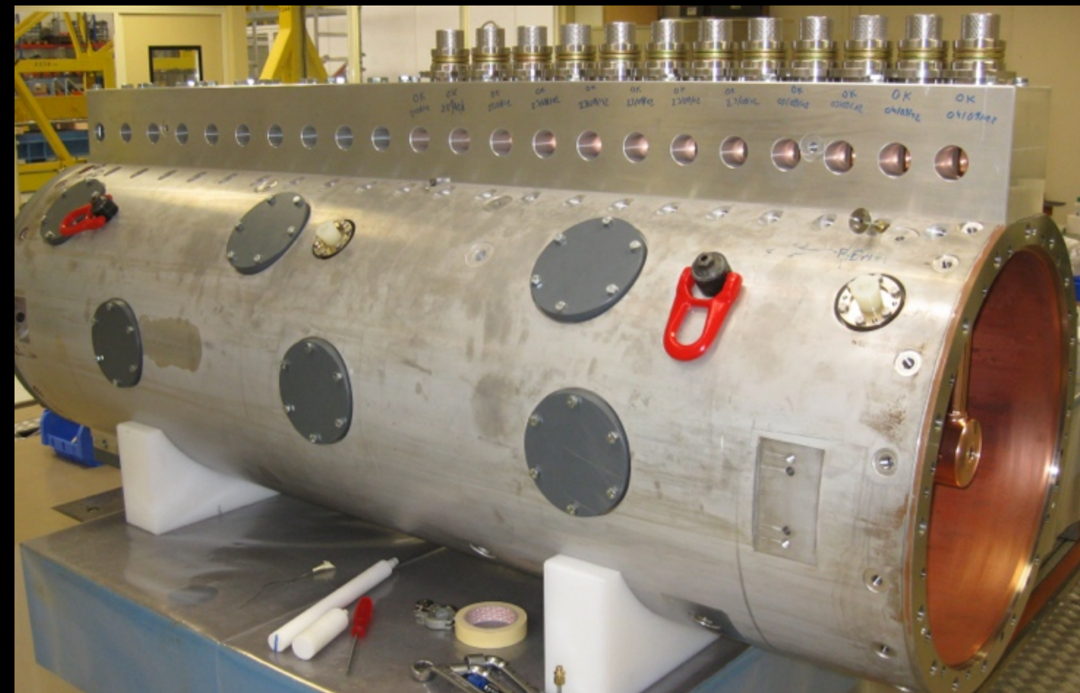
Drift Tube Linac

project eng: S. Ramberger

construction: industry + collaboration (ESS Bilbao)

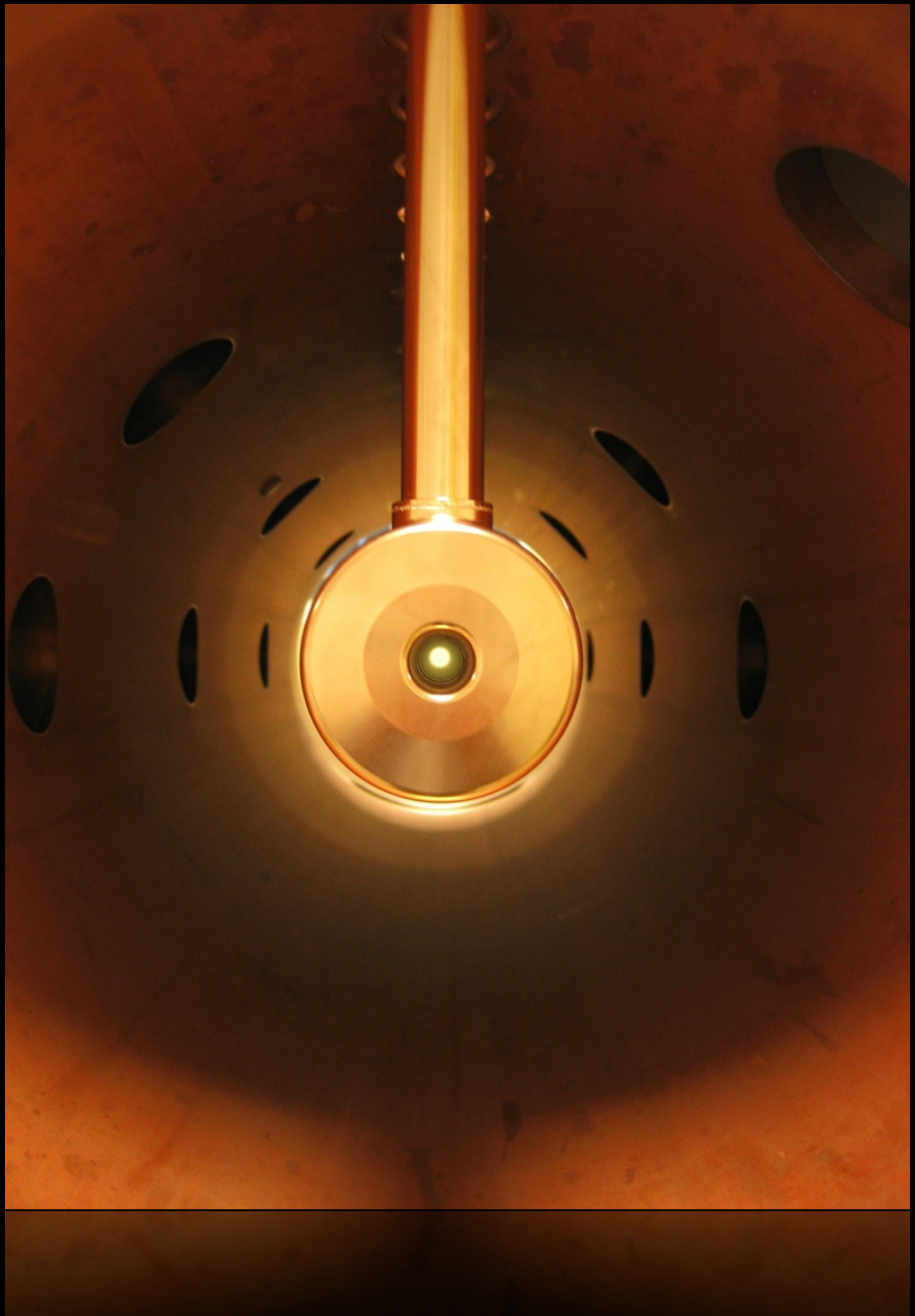
Parameter	Value
frequency	352.2 MHz
energy range	3 - 50.3 MeV
E_0T	2.65 - 2.95 MV/m
synchronous phase	-30 → -26 deg
ZT^2 (linac def., operational value)	44 - 52 MΩ
Q_0 (measured, av. p. module)	~39000 - 43000
cavity length	3.8 - 7,3 m
number of cavities	3
total number of drift tubes	108
peak power/cavity	1/2/2 MW
Kilpatrick	< 1.6

DTL highlights



- Rigid (5 cm thick) steel tanks assembled from <2 m long segments.
- PMQs in vacuum for streamlined drift tube assembly (SNS technology).
- Adjust & Assemble: Tightly toleranced Al girders w/o adjustment mechanism.
- Design for zero maintenance (no diagnostics/steering/EMQs inside DTs).
- Spring loaded metal gaskets for vacuum sealing and RF contacts.
- Easy-to-use mounting mechanism filed for patent.
- Increased gap spacing in first cells to reduce peak fields and potential breakdowns in PMQ fields.

DTL assembly status



- The first tank segment is copper plated and assembled with girder and drift tubes.
- Drift tube installation takes 10 min/item thanks to metal gaskets and ("automatic") alignment.
- Vacuum leak tight.
- First tank completed by the end of 2012, testing in 2013.
- Tank 2&3 to be assembled and tested in 2013.

timeline DTL:

2004	start of a collaboration with VNIIEF and ITEP (Russia) for the design and construction of Linac4 DTL tank
2005	decision to use PMQs
2006-7	start of mechanical design at CERN
2008	**construction of DTL prototype in collaboration with INFN Legnaro**
2009	**successful high-power testing of the CERN/INFN prototype**
2010	filing of patent on the "mounting mechanism" to position drift tubes
2008-10	purchase of **30 tons of raw material (~3000 pieces** of stainless steel cylinders, Cu drift tubes/stems, Al girders, flanges, etc)
2011	**start of construction of tanks (industry) and drift tube parts (collaboration with ESS-Bilbao)**
2012	start of girder construction in industry
today	**assembly of first tank segment at CERN**
start 2013	first tank assembled and ready for testing
2013	assembly and tuning of tank 2,3, low-power testing of tank 1,2,3
2013-14	**installation in Linac4 tunnel and high-power testing**

CCDTL

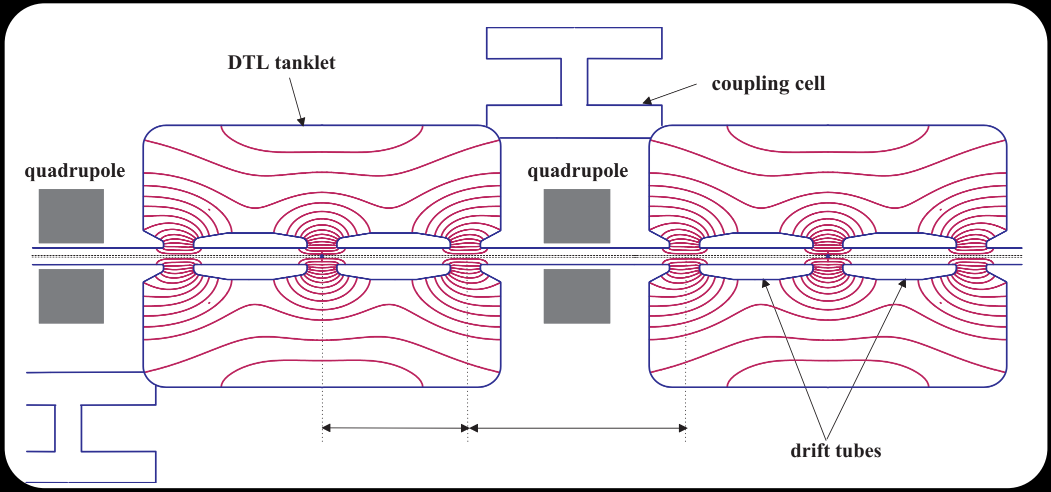
Cell-Coupled Drift Tube Linac

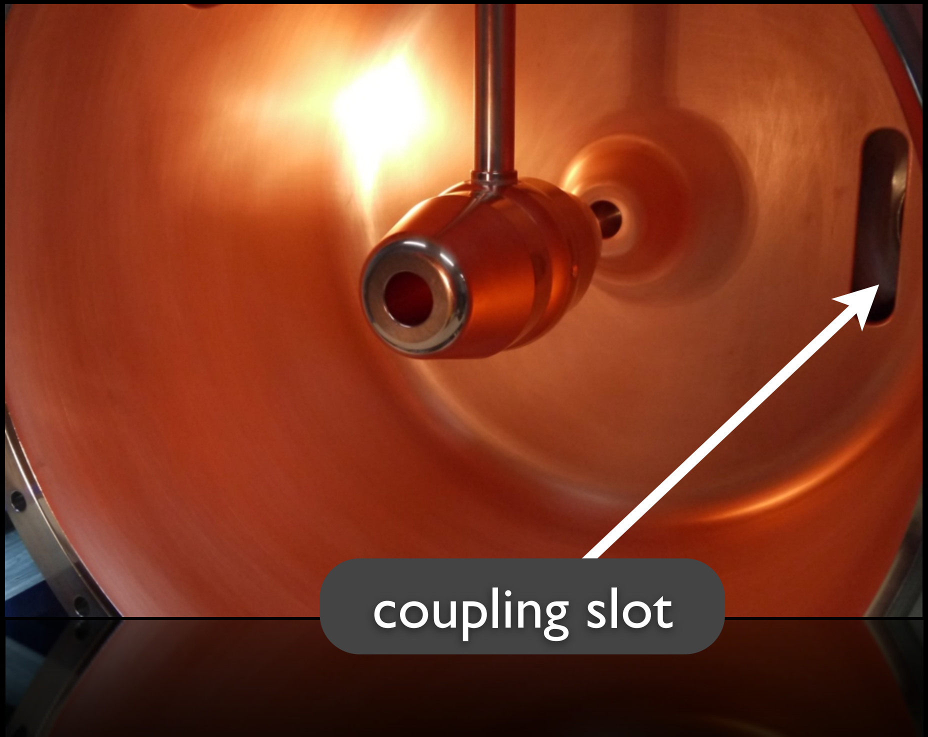
design & construction: BINP, VNIITF

project eng: A. Tribendis (BINP)

Parameter	Value
frequency	352.2 MHz
energy range	50.3 - 102.9 MeV
E_0T	3.6 - 2.7 MV/m
synchronous phase	-20 deg
ZT^2 (linac def., operational value)	40 - 33 MΩ
Q_0 (measured, av. p. module)	~41000 - 44000
cavity length	0.7 - 1.04 m
number of modules	7
cavities per module	3
accelerating gaps per cavity	3
total number of drift tubes	42
peak power/cavity	950 - 1000 kW
Kilpatrick	<1.8

CCDTL highlights

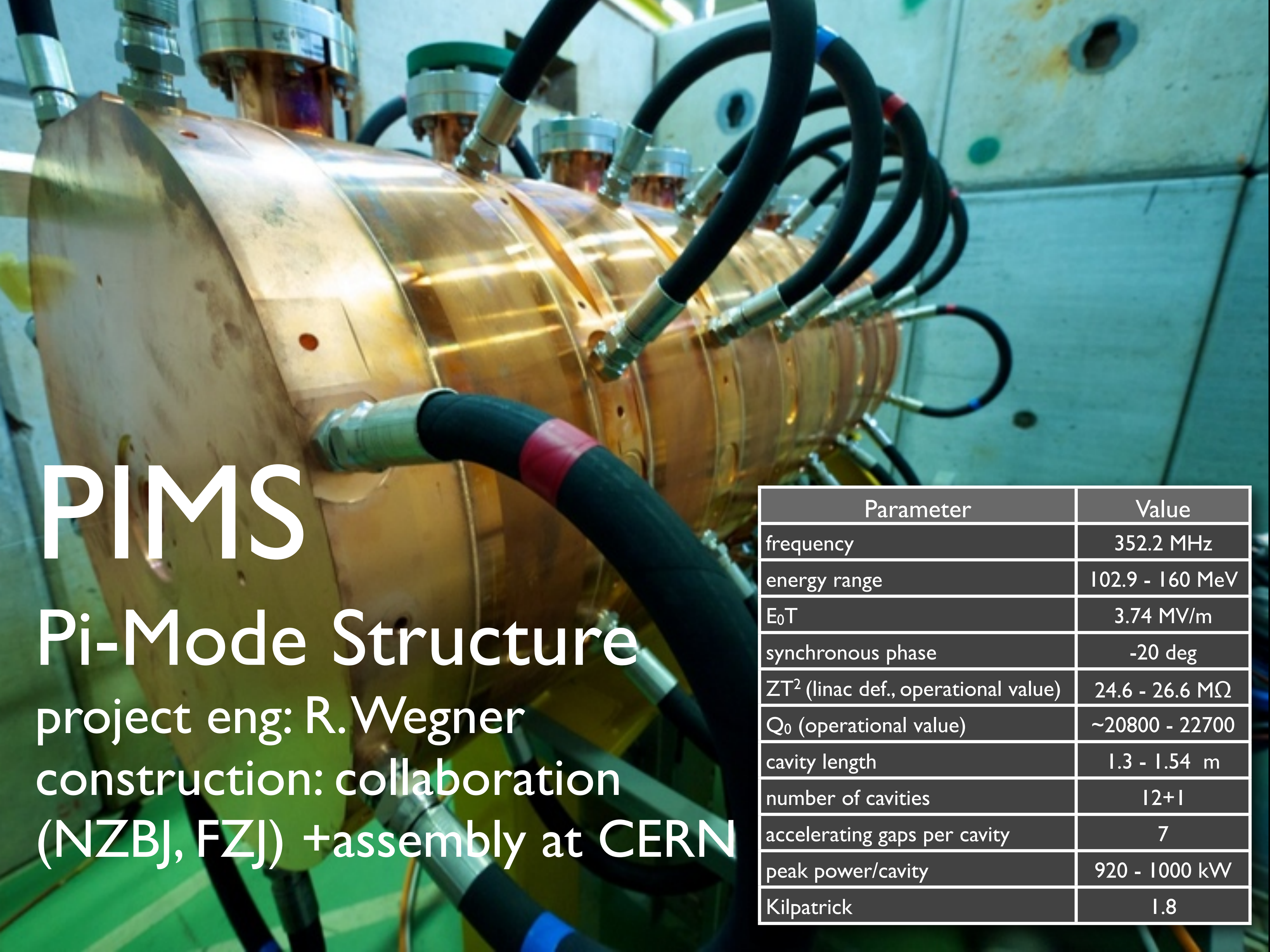




- **First ever use of a CCDTL in an operational machine!**
- 3 tanks/9 gaps per module
- **Alignment** of quads outside of RF structure (easy access),
- **Alignment** of complete module (3 cavities) on support (beam apertures within ±0.3 mm) via mechanical means (successfully tested).
- coupling cell dimensions remain constant for all modules,
- 8 technical meetings (5 in Russia, 3 at CERN),
- France - CERN - Moscow - VNIITF (Snezhinsk) - BINP - Moscow - CERN: **13000 km** until the raw steel has been transformed into cavities,

timeline CCDTL:

1994	J. Billen, F. Krawczyk, R. Wood, L. Young: "A new RF structure for Intermediate Velocity particles"
2000	Conceptual CCDTL design for new proton linac at CERN
2001	13-cell **cold model** in aluminum
2004/5	design/construction of **CERN prototype**: 2 half tanks + 1 coupling cell
2006	successful high-power testing of CERN prototype
2006	construction of **prototype** with 2 complete tanks + coupling cell in Russia (BINP/VNIITF) within **ISTC** contract
2007	**successful high-power testing** of ISTC prototype at CERN
2009	**start of** ISTC **contracts** to construct 7 CCDTL modules for Linac4
Jan. 2010	shipping of **46 tons of raw material (in ~1500 pieces) to Russia**
Nov. 2011	successful vacuum and low-power tests of first complete module at BINP
this week	**delivery of first 2 modules to CERN**
autumn 2012	assembly and high-power tests of first 2 modules
March 2013	delivery of last modules to CERN



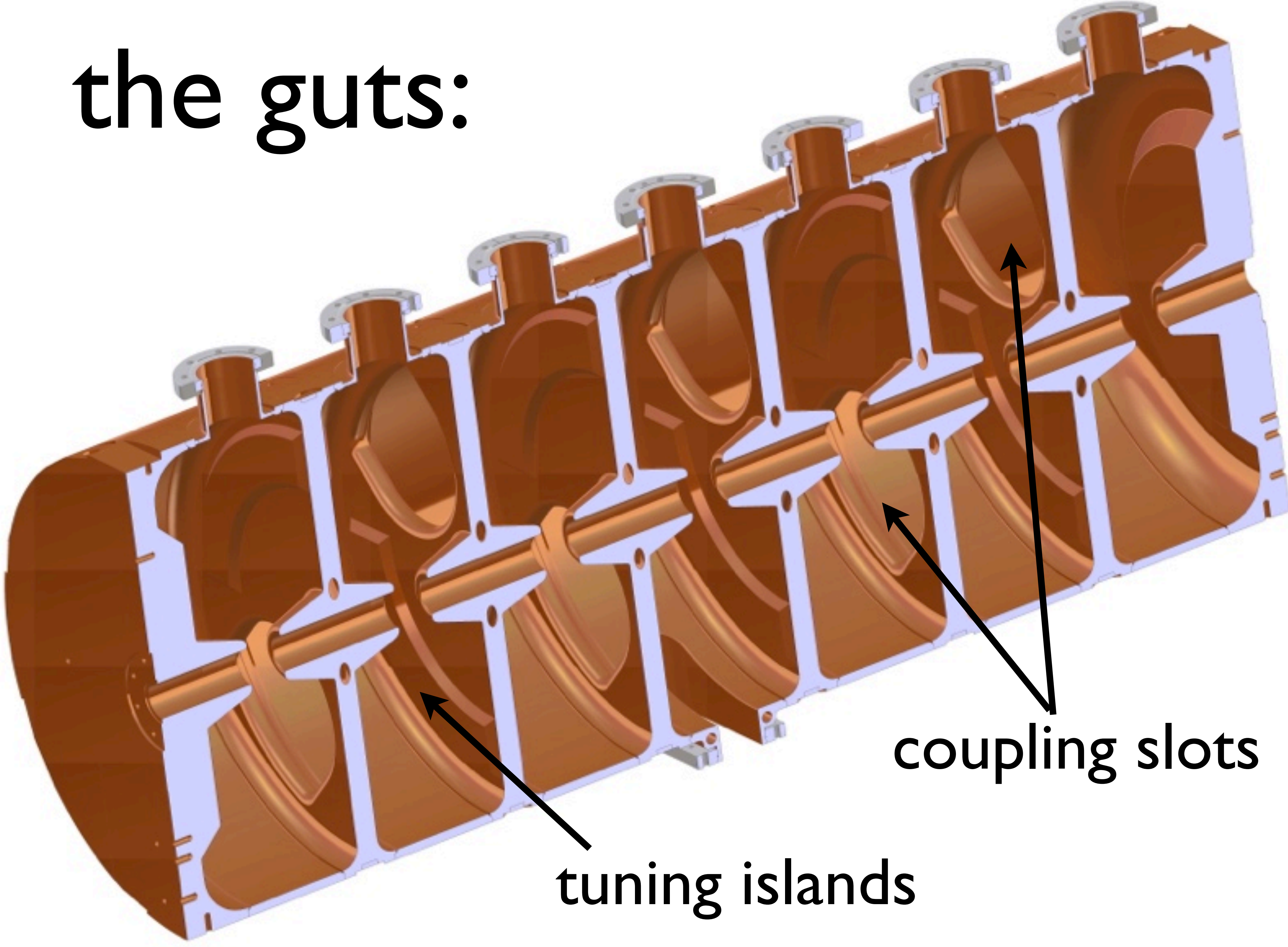
PIMS

Pi-Mode Structure

project eng: R. Wegner
construction: collaboration (NZBJ, FZJ) +assembly at CERN

Parameter	Value
frequency	352.2 MHz
energy range	102.9 - 160 MeV
E_0T	3.74 MV/m
synchronous phase	-20 deg
ZT^2 (linac def., operational value)	24.6 - 26.6 MΩ
Q_0 (operational value)	~20800 - 22700
cavity length	1.3 - 1.54 m
number of cavities	12+1
accelerating gaps per cavity	7
peak power/cavity	920 - 1000 kW
Kilpatrick	1.8

the guts:



PIMS highlights

- same RF frequency (352.2 MHz) as the rest of Linac4,
- 7 cell pi-mode design with strong cell-to-cell coupling (~5%),
- **first-ever use of PIMS in proton linac,**
- coupling slot design optimized for high shunt impedance,
- high power tested 60% above nominal peak fields!
- assembly of discs and rings via EBW to avoid loss of material rigidity during brazing,

timeline PIMS:

1977	5-cell pi-mode structure used in PEP storage ring (electrons) at SLAC (353.2 MHz)
1989	5-cell pi-mode structure used in LEP (electrons) at CERN (352.2 MHz)
2007	**Decision to use PIMS to replace the Side-Coupled Linac (704 MHz)** between 100 - 160 MeV in Linac4 for **low-β proton acceleration**
2007	tendering for 3D forged OFE copper for PIMS construction
2007/8	construction and measurements on scaled **aluminum cold model**
2008	order of 26 t of 3D forged OFE copper (last piece delivered: Nov 2011)
2009/10	design and construction of full size **PIMS prototype at CERN**
2010	**successful high-power testing** at CERN and decision to use prototype as first PIMS cavity in Linac4
Nov. 2010	collaboration with **NCBJ** (National Centre for Nucl. Research, **Poland**, formerly Soltan Inst.) and **FZJ** (Forschungszentrum Jülich, **Germany**) for the construction of 12 PIMS cavities.
Jan. 2011	first shipment of altogether **31 tons of raw material (~1500 pieces)** to Poland
Aug. 2012	most machining and welding operations are qualified, ~half of the discs and rings are rough-machined
autumn 2012	**delivery of first series cavity to CERN**, assembly (EBW), tuning and subsequent high-power testing at CERN,
March 2014	delivery of last PIMS cavity to CERN

lessons learned 1

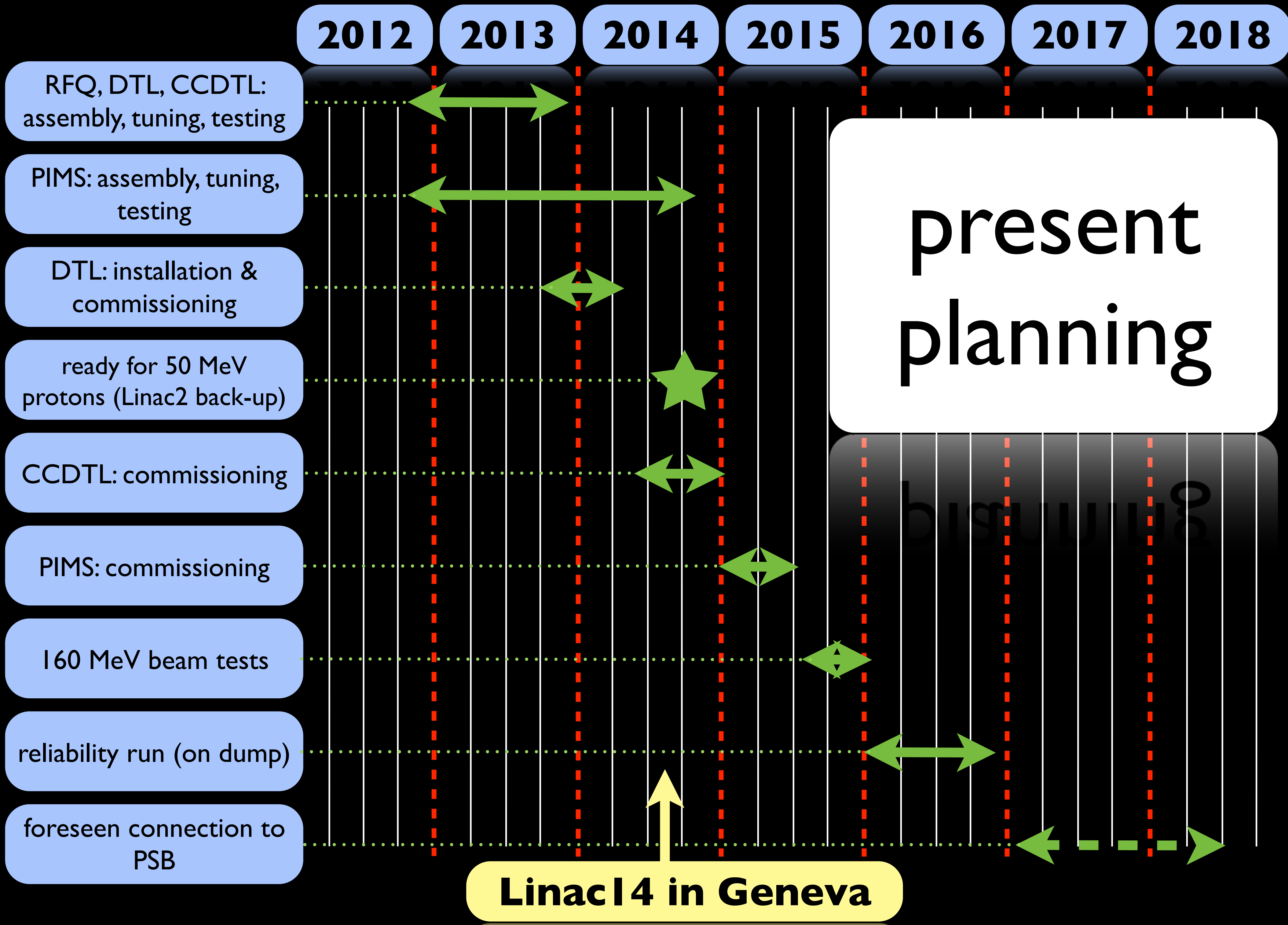
- **Cu-plating:** use of *stainless enables stripping and re-plating with Cu*. When using soft steel all stripped surfaces have to be re-machined (happened with a prototype..). SS has good enough thermal conductivity for 10% duty cycle and could be procured at reasonable cost.
- **Tolerances:** tight tolerances (e.g. for the DTL "adjust and assemble" principle, CCDTL alignment, PIMS assembly) are possible but need i) more effort when selecting companies, ii) often result in long machining times (~80 hours of milling per PIMS disc) ➔ *spending some extra months on the mechanical design to reduce tolerances may save a lot of time later on!*
- **C-shaped metal gaskets**: extensively used in DTL and CCDTL, handling and surface preparation needs a certain learning curve, 6-12 months to qualify a company, several months for delivery, need to order enough spares until you have "learned" to make leak-tight connections. ➔ *vacuum gasket and RF contact in one piece, no organic material in vacuum, no degradation over time, easy dis- and re-assembly,*

lessons learned II

- **Raw materials:** generally all procured & delivered by CERN (eases quality control), 3D forged steel (found only one small void in a critical location) during the construction, 3D forged copper gives excellent EBW results, less problems with deformation during machining, and a guaranteed high yield strength (Rp0.2 > 200 MPa)
  - ➡ *so far no major difficulties related to material quality,*
  - ➡ *It took ~3.5 years to get the last pieces of forged copper, price for PIMS is comparable to the machining cost.*
- **Shipping to/from Russia:** shipping and customs procedures went smoothly due to combined efforts of ISTC, BINP, and CERN.

lessons learned III

- **Project set-up:** beneficial to have *one (competent) partner* (e.g. BINP as CCDTL project leader in Russia) to take care of final design and *complete construction*: i) no problems with interfaces, ii) quality control handled internally, iii) you only qualify general construction procedures (brazing, welding, Cu-plating, surface quality,..) and the final results (vacuum, alignment, RF)
- **Prototyping:** *plan for 2 prototypes!* One in-house to understand and improve your mechanical concept and machining processes. A second with your partner who will do the series production. Alternative: *do your prototyping together with your industrial partner* (forbidden by CERN tendering rules).


2012
2013
2014
2015
2016
2017
2018
RFQ, DTL, CCDTL: assembly, tuning, testing
PIMS: assembly, tuning, testing
DTL: installation & commissioning
ready for 50 MeV protons (Linac2 back-up)
CCDTL: commissioning
PIMS: commissioning
160 MeV beam tests
reliability run (on dump)
foreseen connection to PSB
present planning
Linac14 in Geneva

BINP, Novosibirsk	**CCDTL:** design & construction
CEA, Saclay	**RFQ:** mech. design & measurements
ESS, Bilbao	**DTL, jacks, RF coupler:** production of DTL drift tubes, support for market survey of Spanish industry,
FZJ, Jülich	**PIMS:** port weldings (EBW)
INFN, Legnaro	**DTL**: collaboration on prototype construction, **movable tuners:** construction
ISTC, Moscow	**CCDTL:** contract framework with BINP/VNIITF, financing, customs procedures in Russia
KACST, Riyadh	**DTL:** construction of cold model
NCBJ, Swierk	**PIMS:** machining of all pieces
RRCAT, Indore	**RF coupler**: prototyping & construction
VNIITF, Snezhinsk	**CCDTL**: design & construction
VNIIEF, Sarov	**DTL:** preliminary mechanical design
ITEP, Moscow	**DTL:** preliminary designs

BINP, Novosibirsk	**CCDTL:** design & construction
CEA, Saclay	**RFQ:** mech. design & measurements
ESS, Bilbao	**DTL, jacks, RF coupler:** production of DTL drift tubes, support for market survey of Spanish industry,
FZJ, Jüli	
INFN, L	
ISTC, M	
KACST	
NCBJ, S	
RRCAT,	
VNIITF, Snezhinsk	**CCDTL**: design & construction
VNIIEF, Sarov	**DTL:** preliminary mechanical design
ITEP, Moscow	**DTL:** preliminary designs

Many thanks to the collaborating institutes, our industrial partners and to all the international colleagues, students, fellows, etc who helped and supported us!