Towards a Multi TeV Linear Collider; Drive Beam Generation with CTF3

H.H. Braun / CERN, on behalf of the CTF3 collaboration

- Introduction CLIC & CTF3
- CTF3 status and achievements
- CTF3 outlook

CLIC

CLIC aim:

develop technology for e^-/e^+ collider with E_{CMS}= 3 TeV

covering full LHC physics reach with complementary

lepton collision experiments

Physics motivation:

"Physics at the CLIC Multi-TeV Linear Collider :

report of the CLIC Physics Working Group," CERN report 2004-5

Present goal:

Demonstrate all key feasibility issues by 2010

BASIC FEATURES OF CLIC

- High acceleration gradient

  - "Compact" collider - 3 TeV with overall length < 50 km
  - Normal conducting accelerating structures
  - High acceleration frequency

- Two-Beam Acceleration Scheme

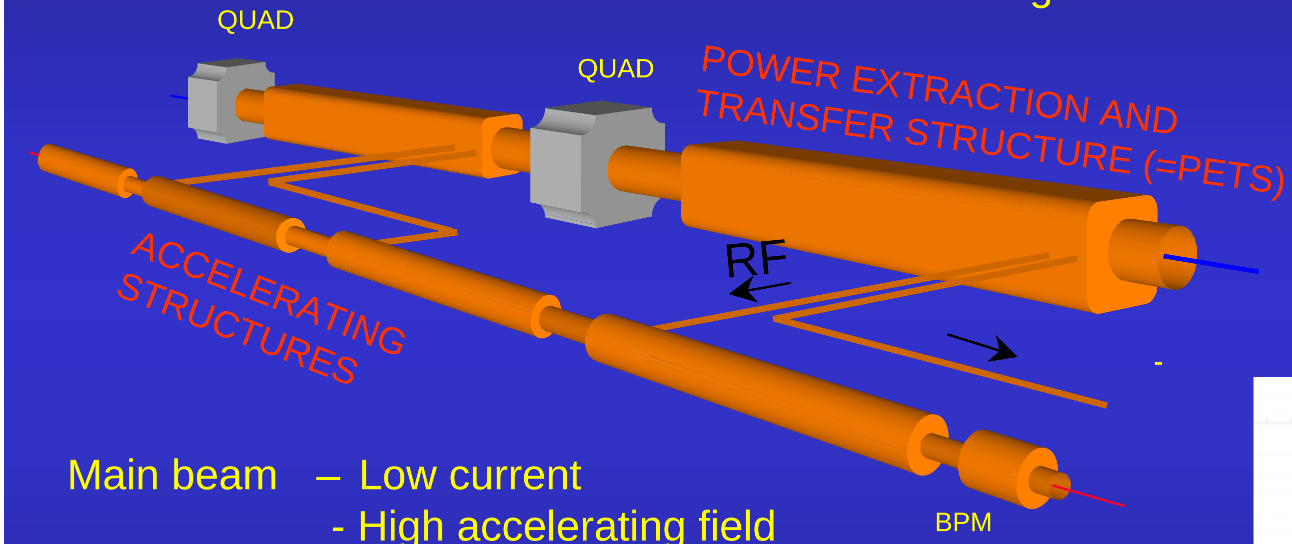
  - Cost-effective & efficient
  - Simple tunnel, no active elements

- Central injector complex

  - "Modular" design, can be built in stages

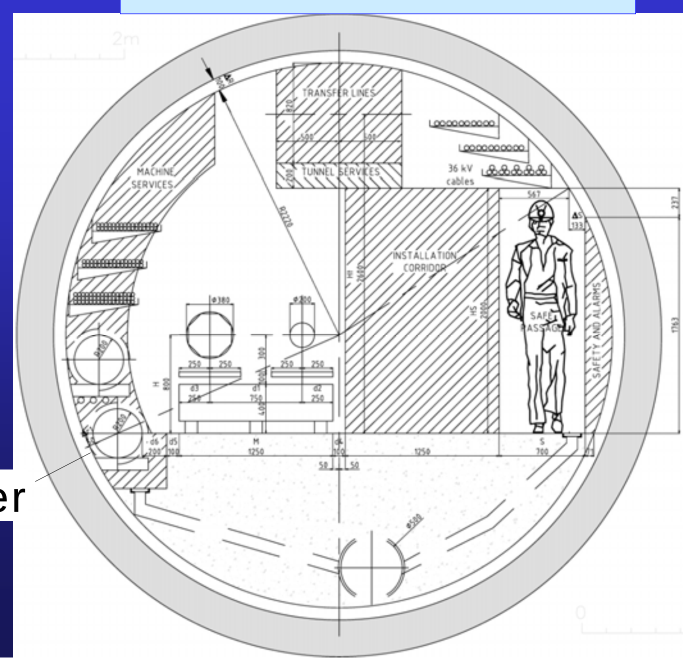
CLIC TWO-BEAM SCHEME

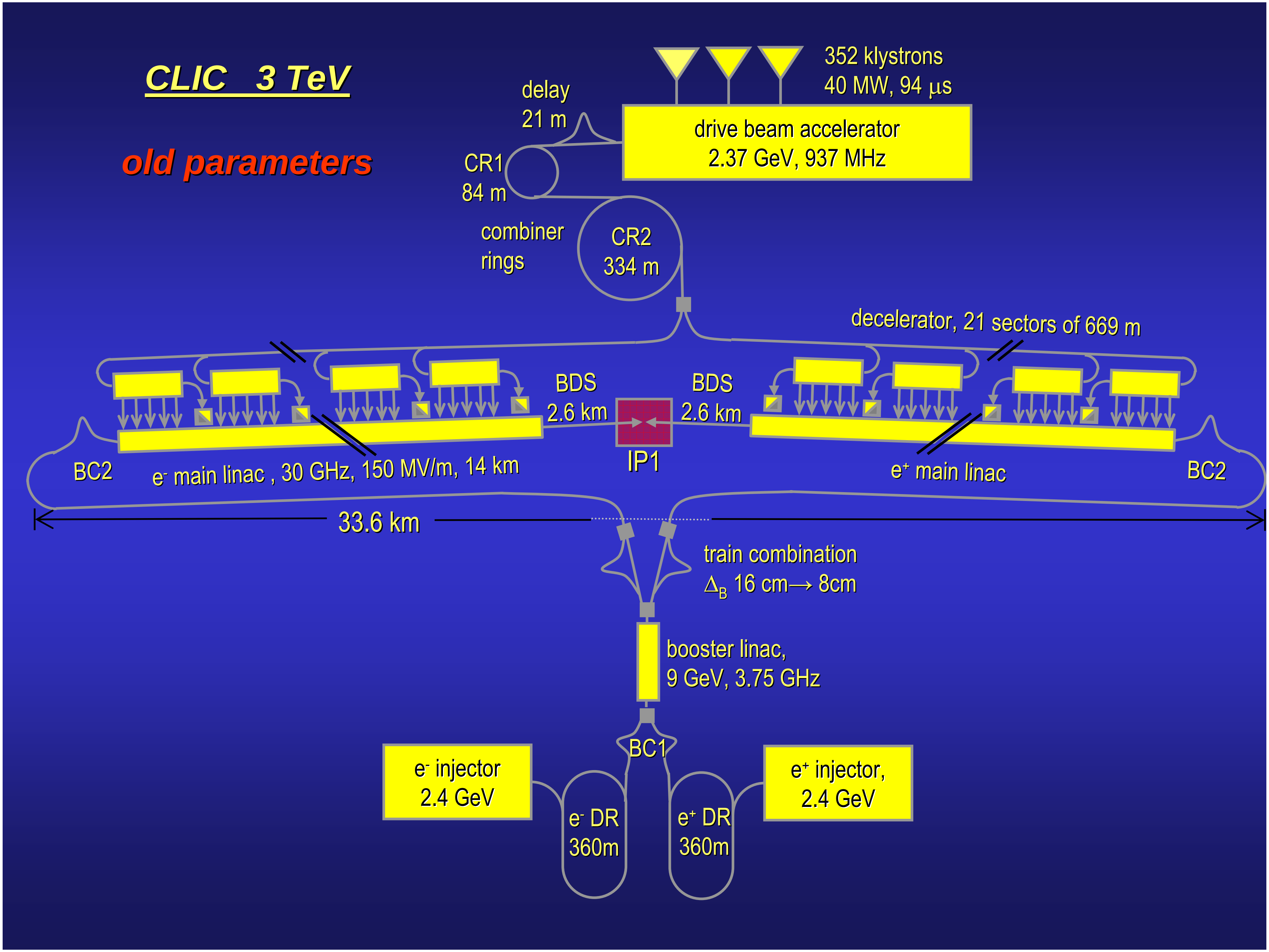
Drive beam - High current
- Low decelerating field



Main beam – Low current
- High accelerating field

CLIC TUNNEL CROSS-SECTION





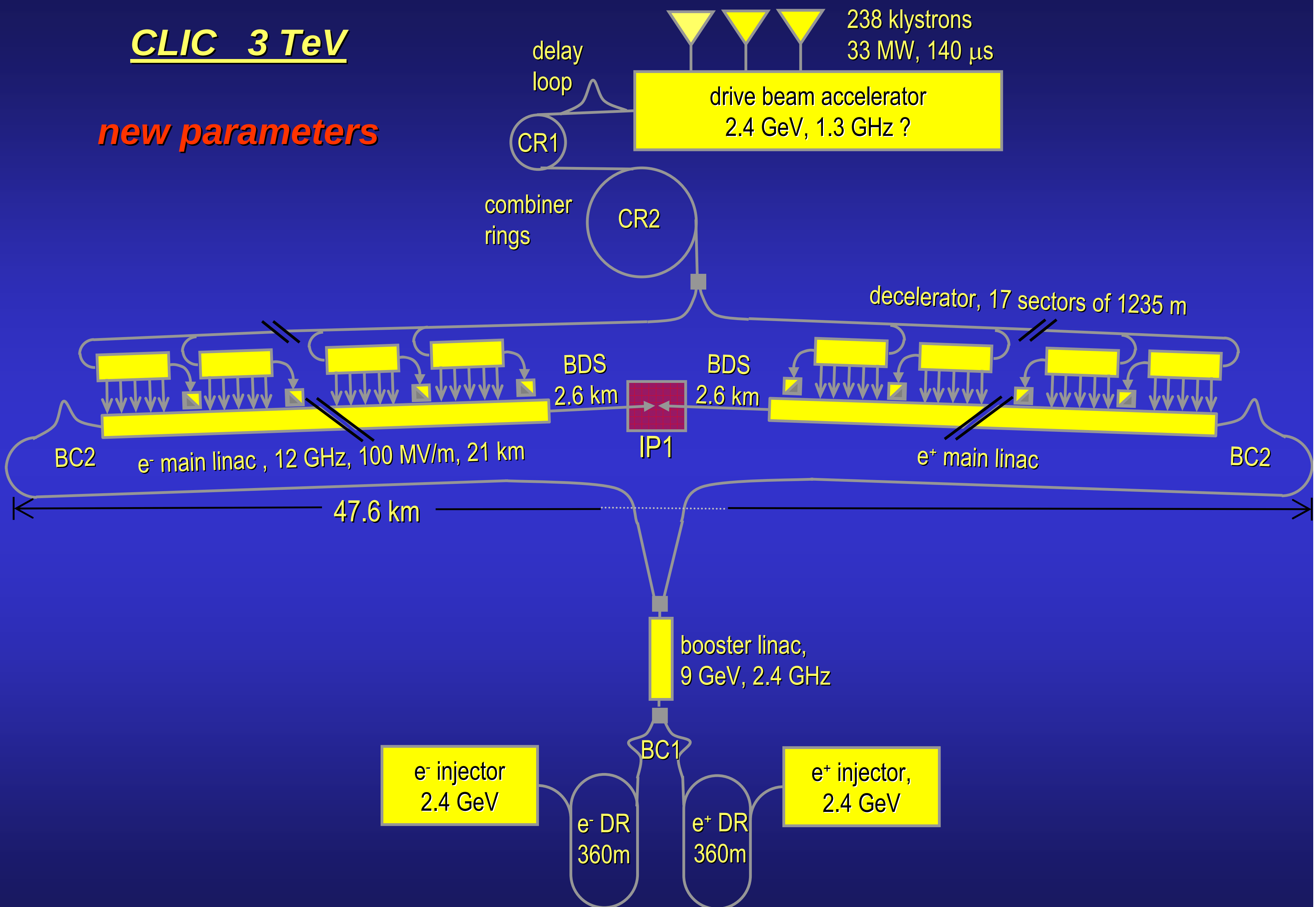
CLIC 3 TeV
old parameters
352 klystrons
40 MW, 94 μs
delay
21 m
drive beam accelerator
2.37 GeV, 937 MHz
CR1
84 m
combiner
rings
CR2
334 m
decelerator, 21 sectors of 669 m
BDS
2.6 km
BDS
2.6 km
IP1
BC2
e- main linac , 30 GHz, 150 MV/m, 14 km
e+ main linac
BC2
33.6 km
train combination
Δ_B 16 cm→ 8cm
booster linac,
9 GeV, 3.75 GHz
BC1
e- injector
2.4 GeV
e+ injector,
2.4 GeV
e- DR
360m
e+ DR
360m

Next slides resembles almost the previous, but we have changed 6 details.

Who finds them first ?

CLIC 3 TeV

new parameters



Recent changes of key CLIC parameters

Main Linac RF frequency	**30 GHz ⇒ 12 GHz**
Accelerating field	**150 MV/m ⇒ 100 MV/m**
Overall length @ E_{CMS}= 3 TeV	**33.6 km ⇒ 47.6 km**

Why ?

Very promising results of earlier Molybdenum test structures not reproduced for test conditions closer to LC requirements (i.e. long RF pulses, low breakdown rate, structures with HOM damping)

Copper structure tests don't indicate advantage of frequencies>12 GHz for achievable gradient

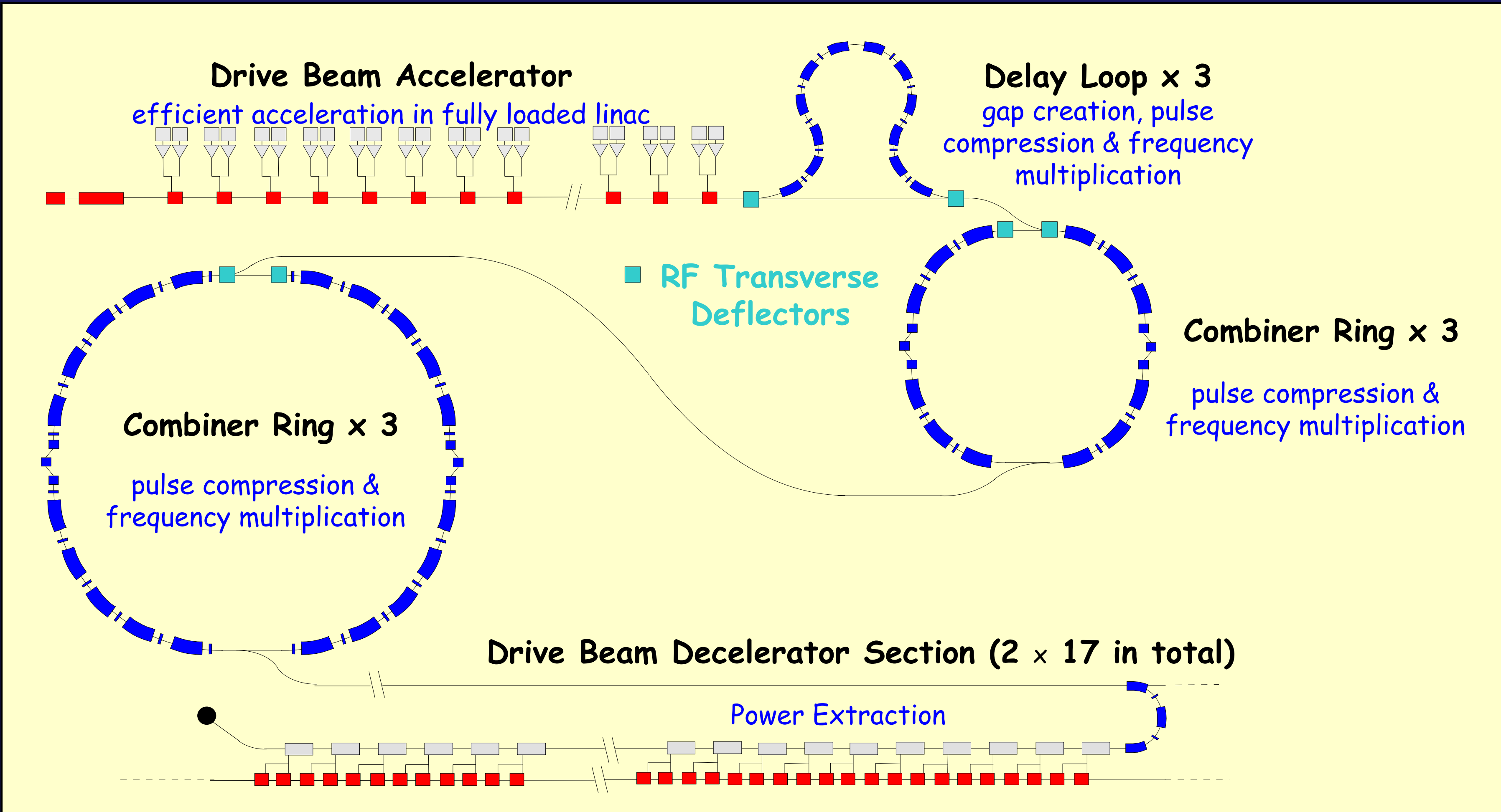
Parametric cost model indicates substantial cost savings for 12 GHz/100 MV/m (flat minimum for this parameter range)

Increase chance of feasibility demonstration by 2010

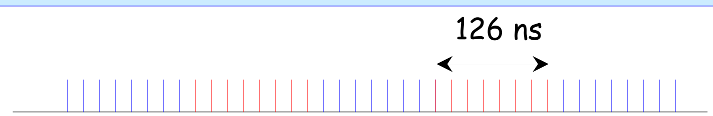
100 MV/m is lowest gradient for a 3 TeV machine

⇒ **See Walter Wuensch's talk Thursday**

CLIC RF power source layout

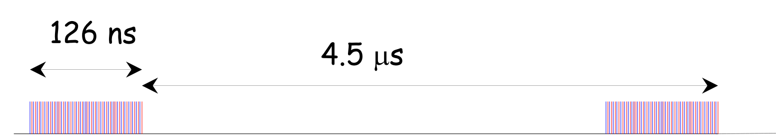


Drive beam time structure - initial



100 μs train length - 32 x 21 x 2 sub-pulses - 5.7 A
2.5 GeV - 64 cm between bunches

Drive beam time structure - final



2 x 17 pulses - 180 A - 2 cm between bunches

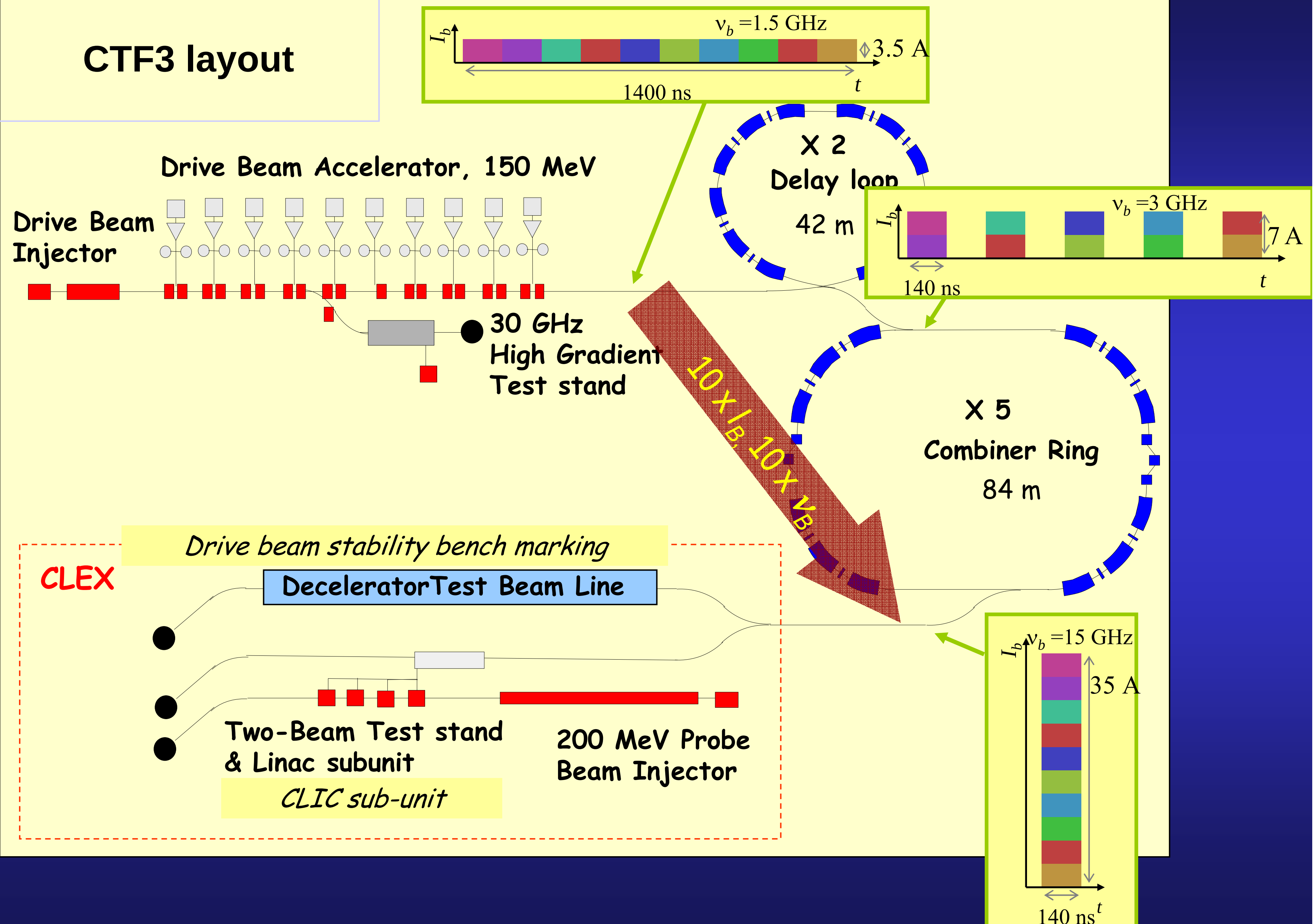
Motivation and Goals of CTF3 collaboration

- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - full beam loading accelerator operation
  - electron beam pulse compression and frequency multiplication using RF deflectors

- Provide the RF power to test the CLIC accelerating structures and components

- ***Tool to demonstrate until 2010 CLIC feasibility issues identified by ILC-TRC in 2003***

CTF3 layout



ν_b =1.5 GHz
3.5 A
1400 ns
t
X 2
Delay loop
42 m
ν_b =3 GHz
7 A
140 ns
t
Drive Beam Accelerator, 150 MeV
Drive Beam
Injector
30 GHz
High Gradient
Test stand
10 x I_B, 10 x ν_B
X 5
Combiner Ring
84 m
ν_b =15 GHz
35 A
140 ns
t
Drive beam stability bench marking
CLEX
DeceleratorTest Beam Line
Two-Beam Test stand
& Linac subunit
CLIC sub-unit
200 MeV Probe
Beam Injector

CTF3 collaboration official members

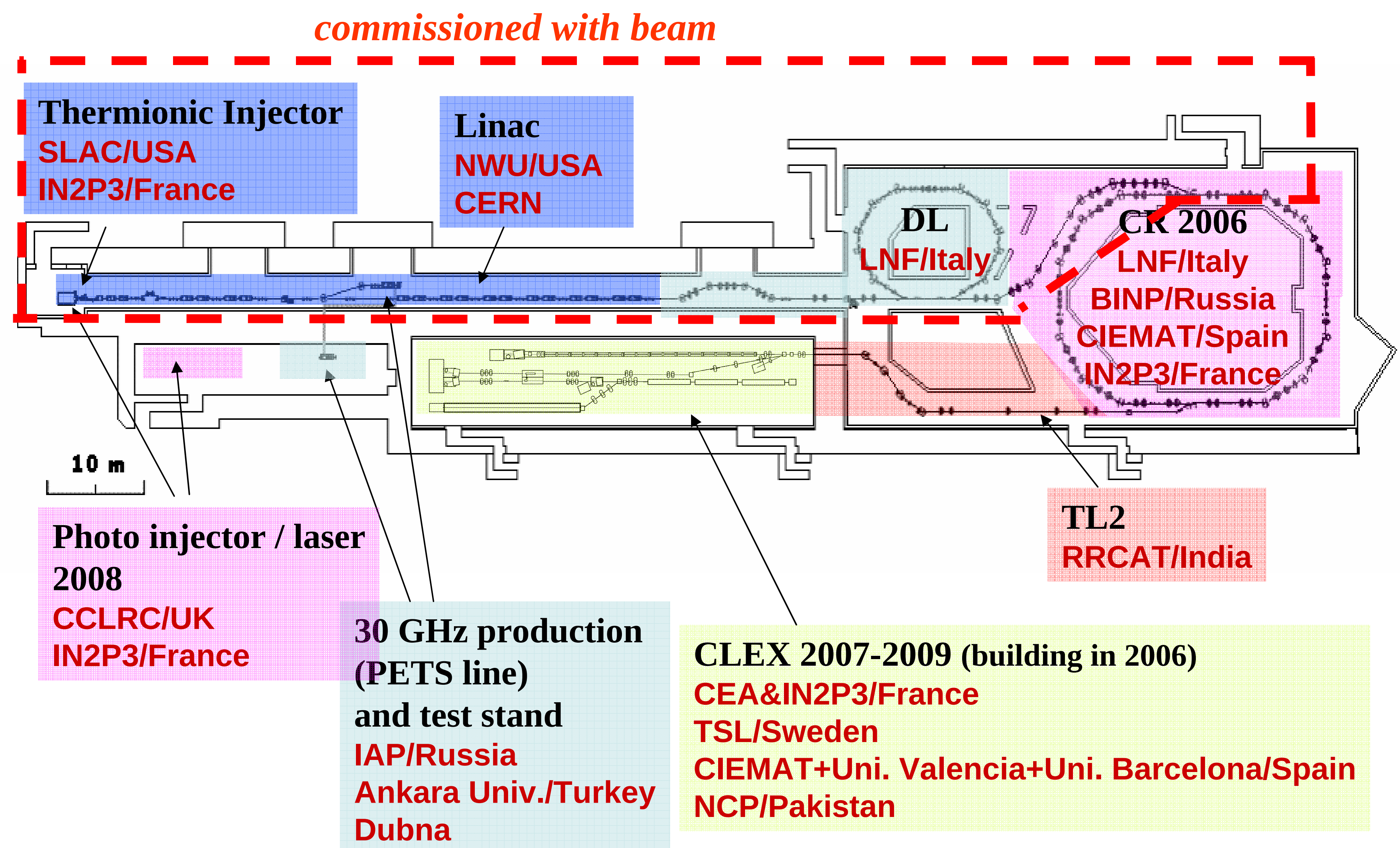
Country	Institute
20 member states	CERN
Finland	Helsinki Inst. of Physics
France	DAPNIA
	LAL
	LAPP
India	BARC
	RRCAT
Italy	LNF
Pakistan	NCP
Russia	BINP
	IAP
	JINR
Spain	CIEMAT
	IFIC
	UPC
Sweden	Uppsala University
Switzerland	PSI
Turkey	Ankara Universities
USA	NWU
	SLAC

collaboration board

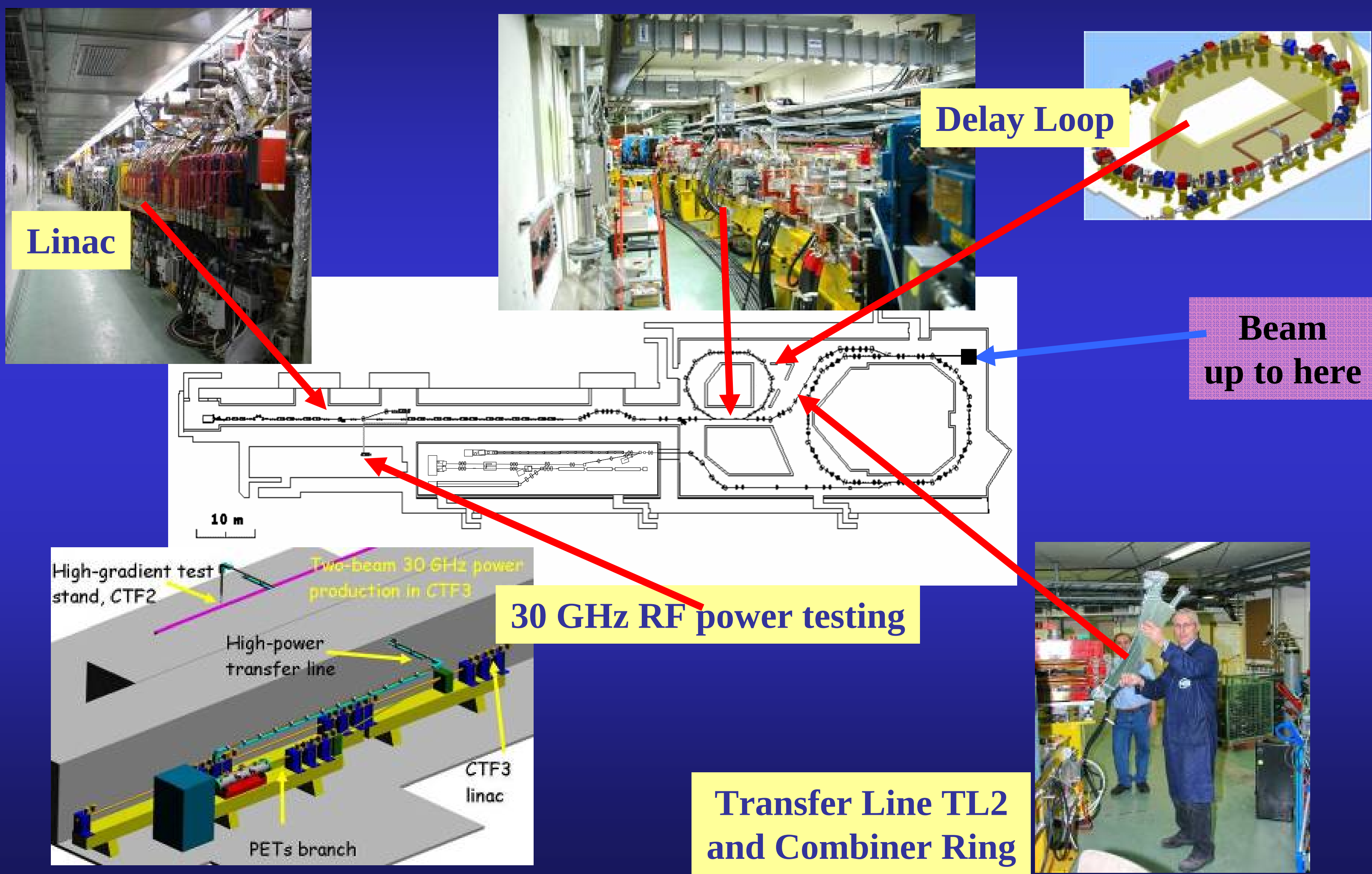
chairman
M. Calvetti / LNF

spokesperson
G. Geschonke / CERN

CTF3 build by a collaboration like a particle physics experiment



CTF3 in 2006

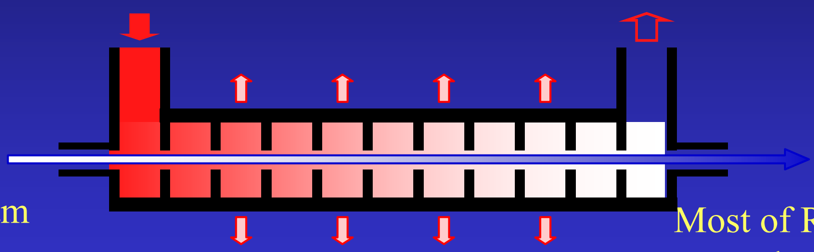


Linac
Delay Loop
Beam
up to here
10 m
High-gradient test
stand, CTF2
Two-beam 30 GHz power
production in CTF3
High-power
transfer line
CTF3
linac
PETs branch
30 GHz RF power testing
Transfer Line TL2
and Combiner Ring

Fully beam loading operation in CTF3

RF in

No RF to load



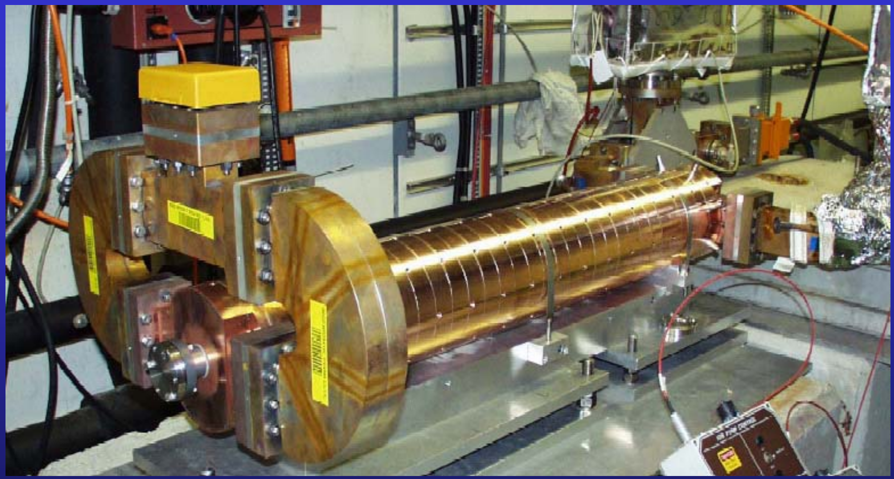
High beam current

Most of RF power to the beam

"short" structure - low Ohmic losses

CTF3 Drive Beam Acc. Structures (3 GHz) – SICA (Slotted Iris – Constant Aperture):
- 32 cells
- 1.2 m long
- $2\pi/3$ mode
- 6.5 MV/m av. acc. gradient for 3.5 A beam current
- HOM damping slots

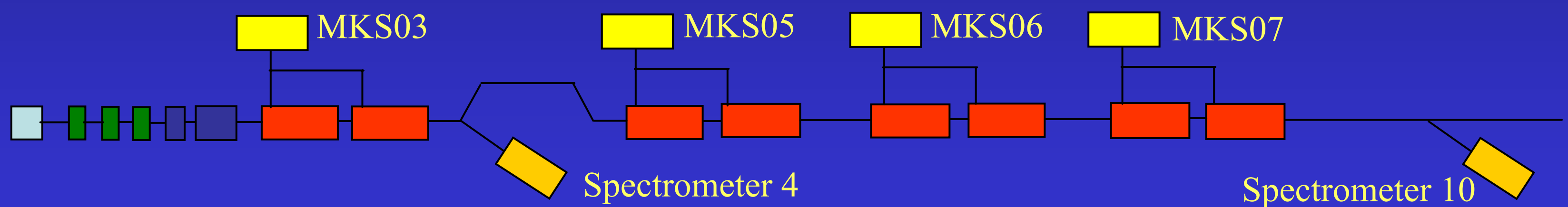
theoretical RF-to-beam efficiency: 96%



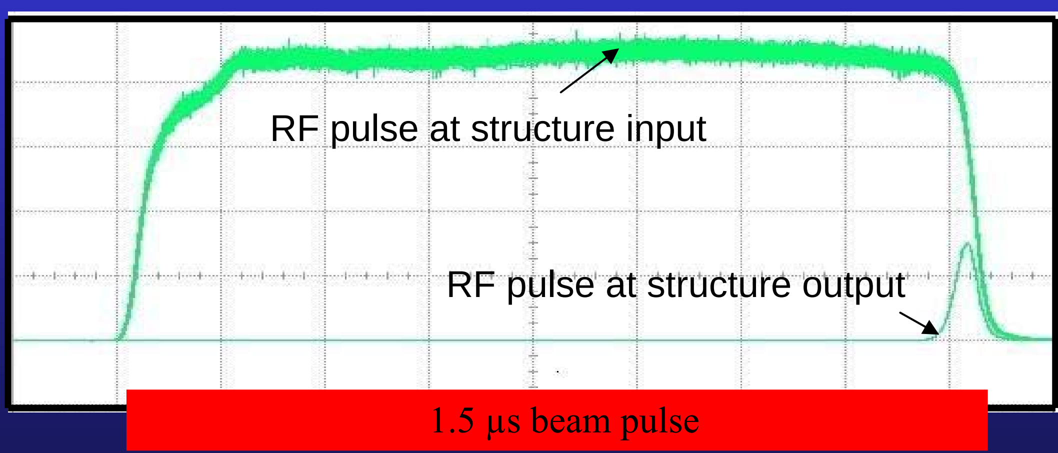
Full beam loading operation in CTF3 – Demonstration for CLIC operation

CLIC: no RF pulse compression
length of the drive beam pulse: 100 μs

Demonstration at CTF3:



Setup: no RF pulse compression for this experiment (with exception of MKS03)
1.5 μs long pulses
Adjust RF power and phase and beam current, that fully loaded condition is fulfilled



analog signal

Full beam loading operation in CTF3 – Demonstration for CLIC operation

Idea: Delay always one klystron pulse after the beam pulse and measure relative energy in spectrometer 10 and compare with calculations.

An exact knowledge of the structure input power, the beam current and the energy gain is essential.

MKS05	MKS06	MKS07	
in	in	in	total energy
out	in	in	lower energy

compare to theoretical energy gain (input power, beam current)

↓

- "missing" acceleration (energy gain per structure)
- deceleration due to direct beam loading

↑

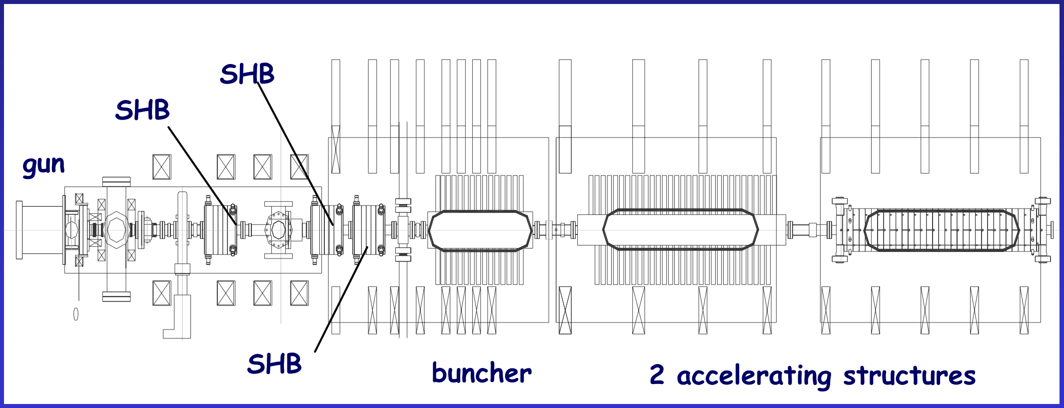
from calculations (beam current)

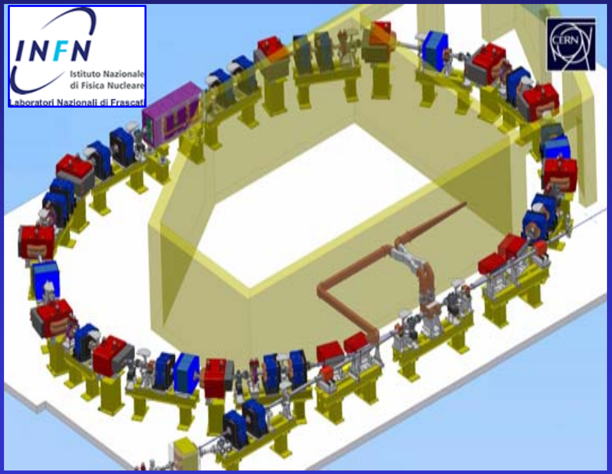
measured RF-to-beam efficiency: 95.3 %

Theory: 96% (~4 % ohmic losses)

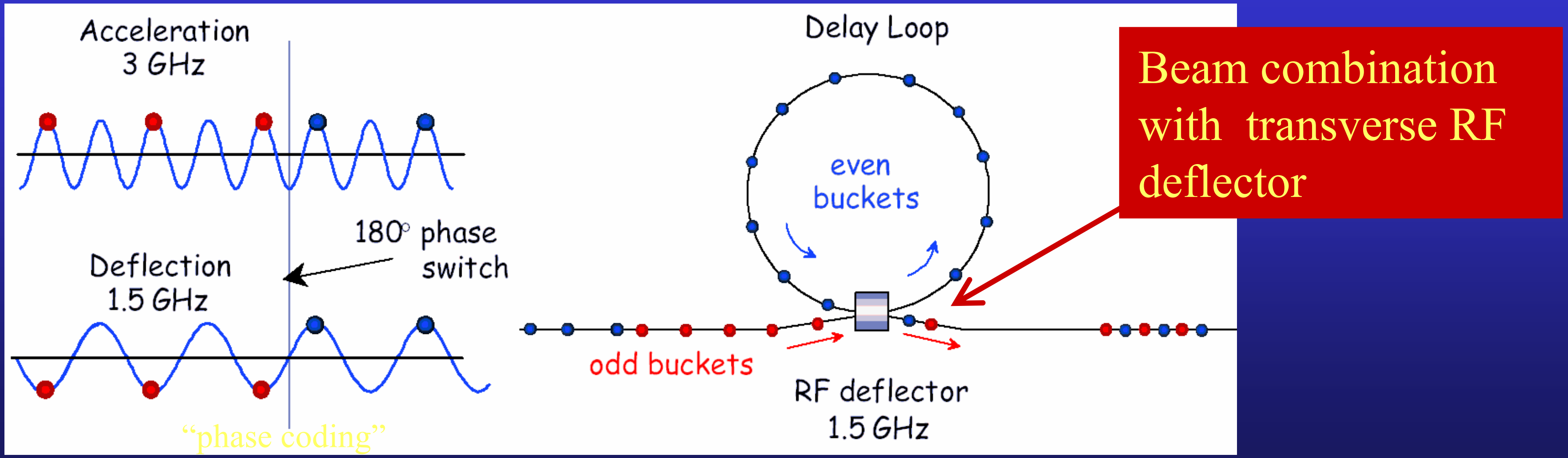
How does the bunch frequency multiplication work?

CTF3 Injector with 3 SHB cavities (1.5 GHz)





Phase coding and bunch frequency multiplication in delay loop

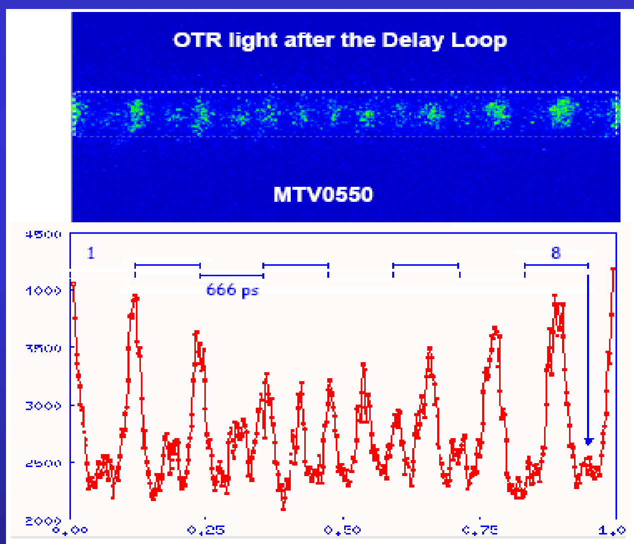


Commissioning of the Delay Loop – **SHB system**

Key parameters for the SHB system: 1) time for phase switch < 10 ns (15 1.5 GHz periods)
2) satellite bunch population < 7 %
(particles captured in 3 GHz RF buckets)

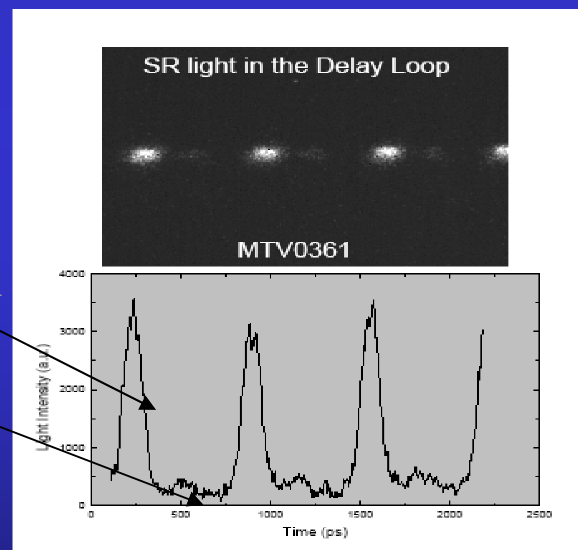
phase switch:

satellite bunch population:



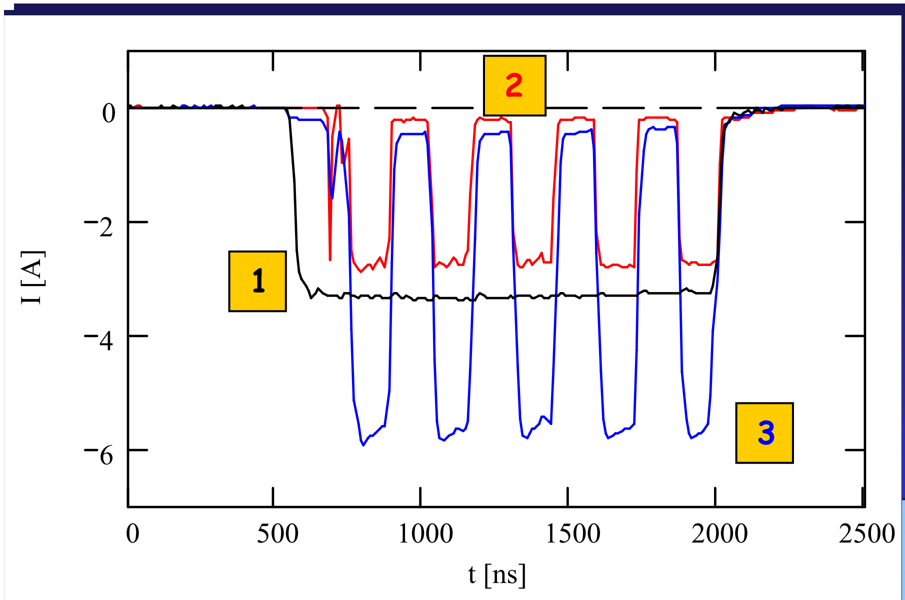
main bunch

satellite bunch



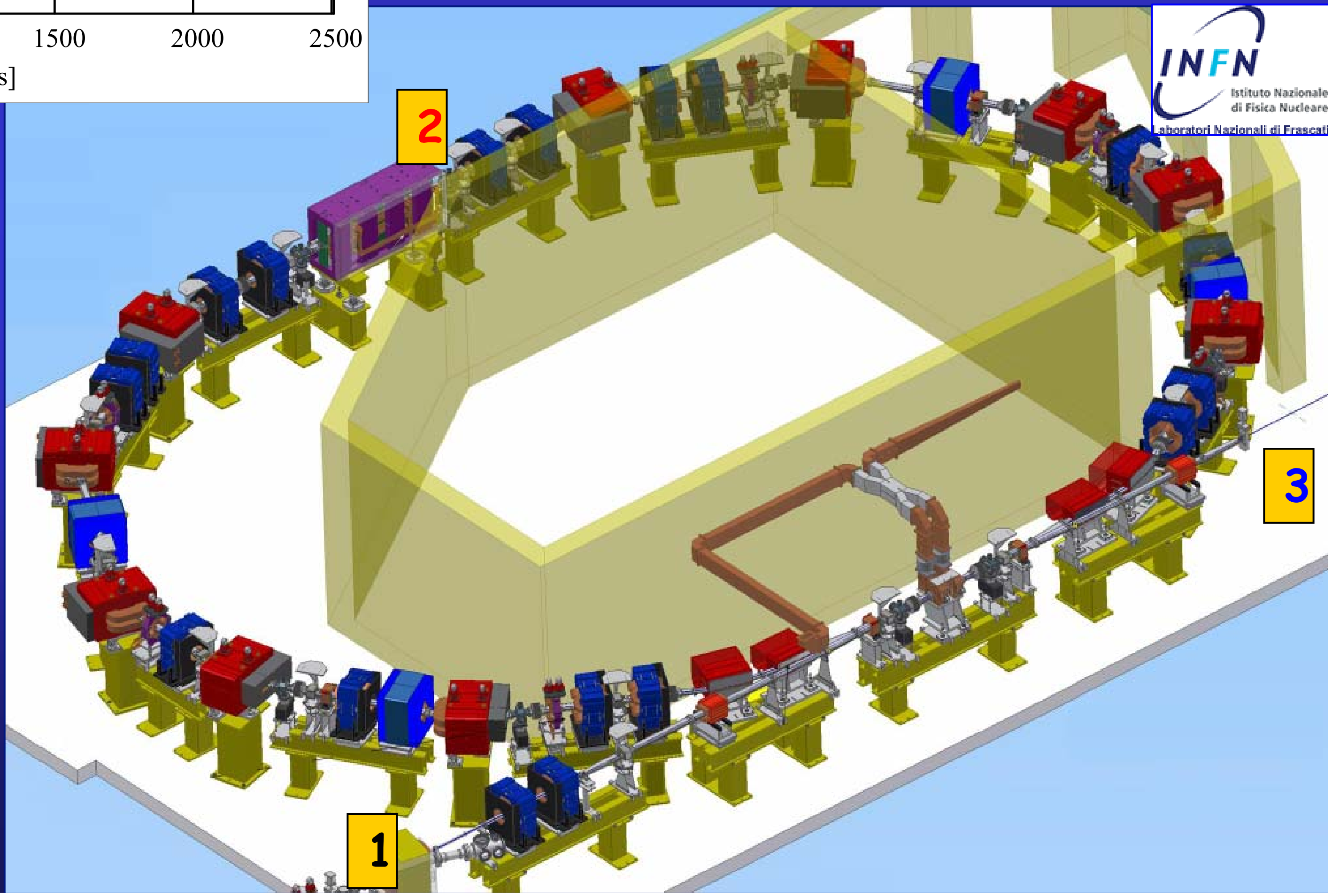
Phase switch is done within eight 1.5 GHz periods **(<6 ns).**

Satellite bunch population was estimated to **~8 %.**



Beam recombination in the Delay Loop (factor 2)

⇒ **More details Fabio Marcellini's talk** (Thursday)



Summary of recent CTF3 Achievements

- Nominal beam production and stable acceleration of 3.5 A beam with full pulse length without significant emittance growth. Wakefields kept under control with HOM damping+detuning and strong transverse focusing.
  Measured performance is consistent with predictions from beam dynamics simulations.
- Measured RF power to beam energy transfer efficiency of 95% in fully loaded operation for normal conducting linac !
  Proves that drive beam production is as efficient as predicted.
- Demonstration of bunch frequency multiplication with delay loop using RF deflector cavities and phase coding with rapidly phase switched subharmonic buncher. This is a key ingredient to achieve bunch train compression.
- Routine 24h, 7 days a week operation of fully loaded linac for 30 GHz production $\Rightarrow$ fully loaded operation can be very reliable and stable.

Next step: Combiner Ring commissioning spring 2007

CERN: Layout, infrastructure, cabling, magnets, power supplies, installation
CIEMAT: Septa magnets, sextupoles, correctors, extraction Kickers
INFN: RF deflectors, wiggler, vacuum chambers, BPM (BPI)
LAPP: BPM electronics
LURE: quadrupoles
BINP: magnet realization

Some remarks about CLIC parameter change and CTF3

Bunch repetition frequency of drive beam can be readily chosen as
6, 9, 12, 15 GHz by varying number of stacking turns in combiner ring
and fine tuning of ring circumference with wiggler.
Drive beam can produce RF on any harmonic of these frequencies.
This makes adaptation of CTF3 drive beam to new frequency straight forward !

Definitive frequency choice was urgent, since ordering of RF components
for CLEX two beam test has to start now.

Functionality and Specifications for TL2 (commissioning spring 2008)

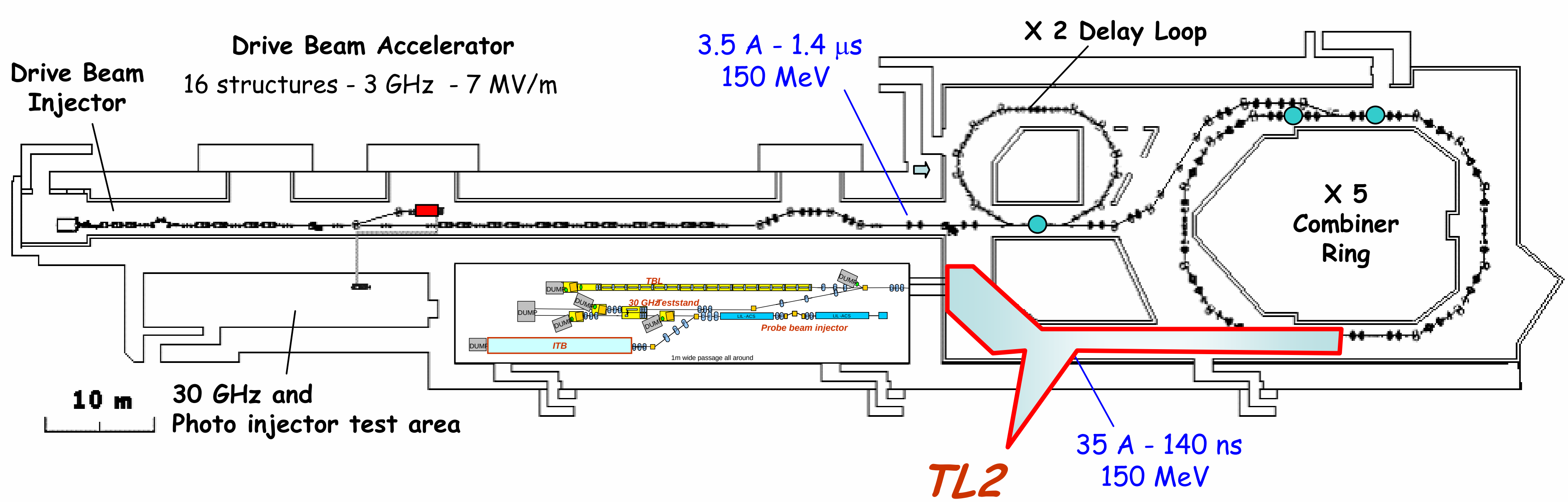
Transport of drive beam from combiner ring extraction to CLEX

Bunch length manipulation with R_{56} variable in the range $-0.35\text{m}<R_{56}<0.35\text{m}$, with compensated T_{566} .

Emittance dilution < 10% (for 150 MeV, $\varepsilon_{x,y}$=100 μm)

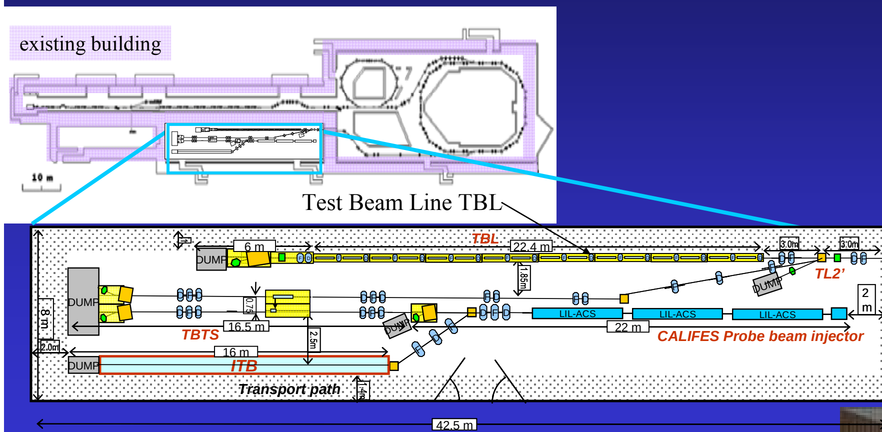
Vertical achromat for 50 cm vertical displacement to adapt for different floor level of CLEX relative to EPA building

"Tailclipper" consisting of a fast kicker plus a collimator dump to adjust beam pulse length for drive beam in two beam test stand and TBL



For more details ⇒ talk by Amalendu Sharma (Tuesday)

CLEX building



Construction on schedule
Equipment installation from May 2007,
Beam foreseen from March 2008

CLEX Glossary

CLEX=CLIC EXperimental area

TBTS=Two Beam Test Stand
Testbed for 12 GHz RF tests of drive beam decelerating structures (PETS) and main beam accelerating structures.
Demonstration of two beam acceleration

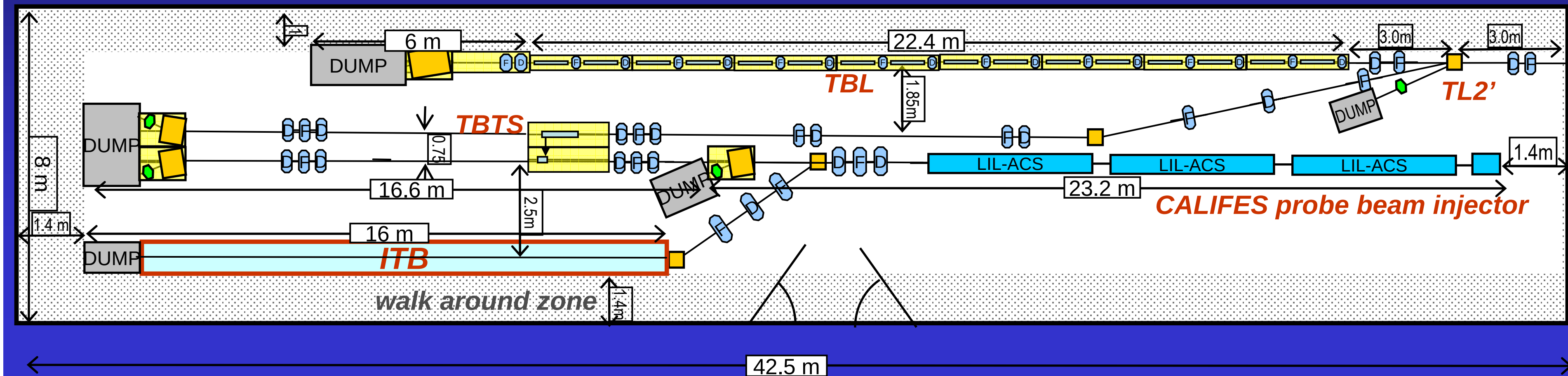
TBL=Test Beam Line
Feasibility demonstration of CLIC drive beam decelerator

CALIFES=Concept d'Accélérateur Linéaire pour Faisceau d'Electrons Sonde
3 GHz probe beam injector to simulate main beam in TBTS

TL2'
switchyard for drive beam and drive beam diagnostics

ITB=Instrumentation Test Beam
Option for 2nd beamline connected to CALIFES for development and test of beam diagnostic equipment

Layout of CLEX-A (A=Accelerator housing) floor space



Space reservations

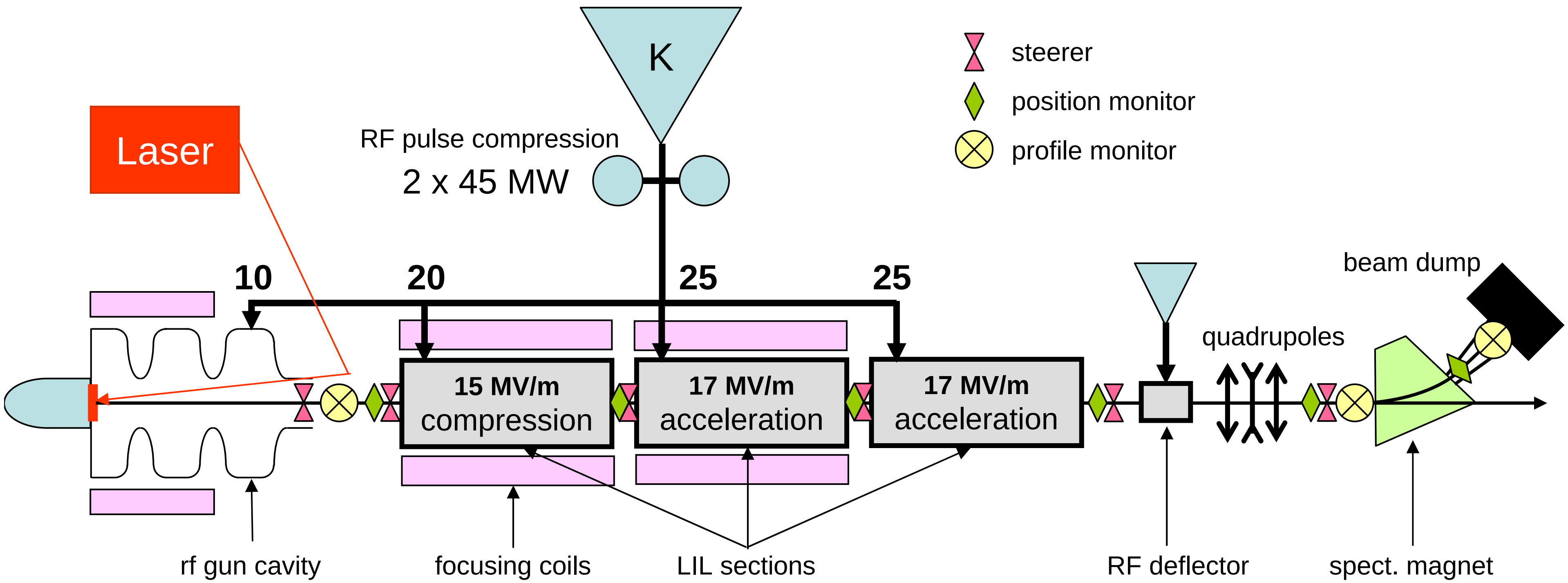
CALIFES	**23.2 m from cathode manipulator arm to exit flange of spectrometer**
TBTS	**16.6 m from output spectrometer to end of beam dump**
TBL	**31.4 m from dogleg bend to end of beam dump**
ITB	16.0 m from 2nd dogleg magnet to end of beam dump (optional, not funded yet)

180 MeV Probe Beam Injector

CALIFES =Concept d'Accélérateur LInéairepour Faisceau d'ElectronsSonde

choice of architecture :

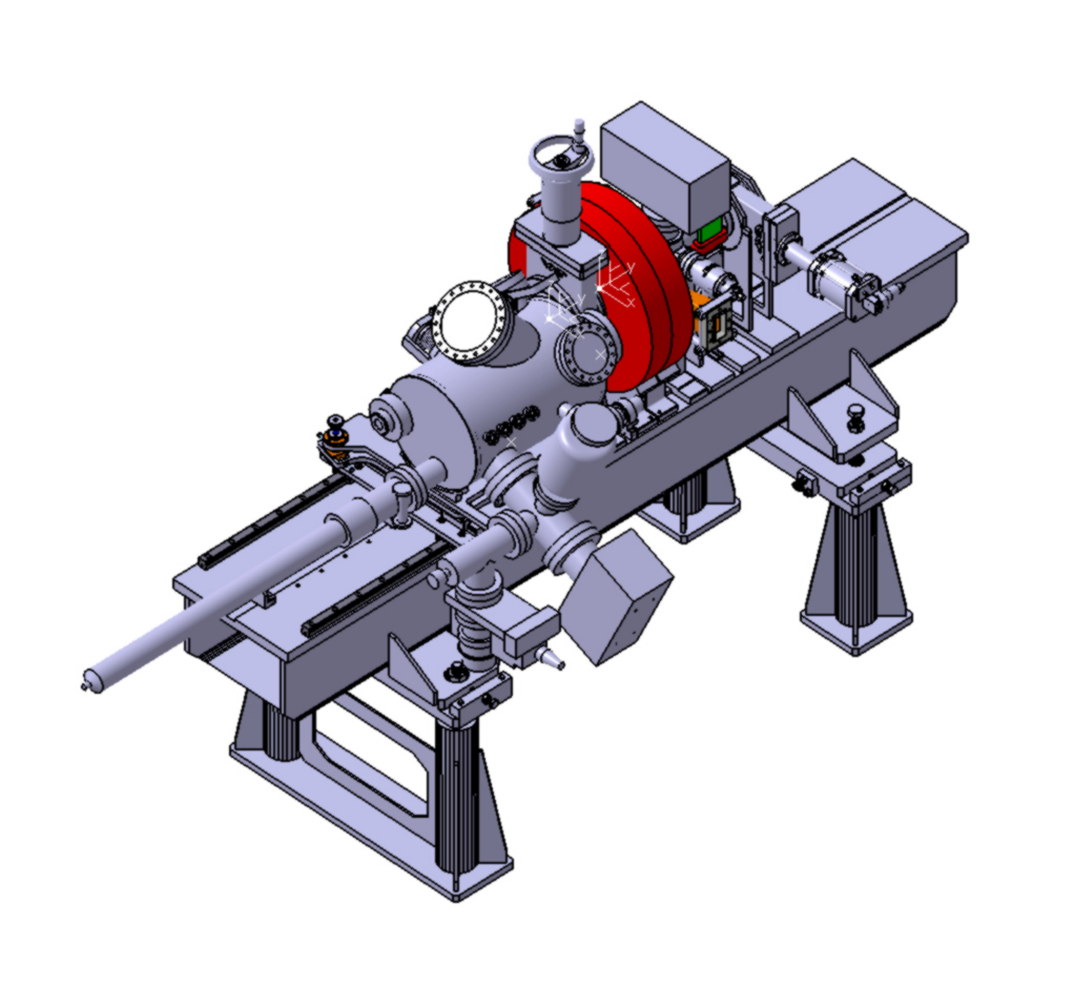
- 1 photo-injector
- 3 LIL sections: 1 for compression and 2 for acceleration
- 1 beam line with diagnostics (leading to 2-beam teststand)



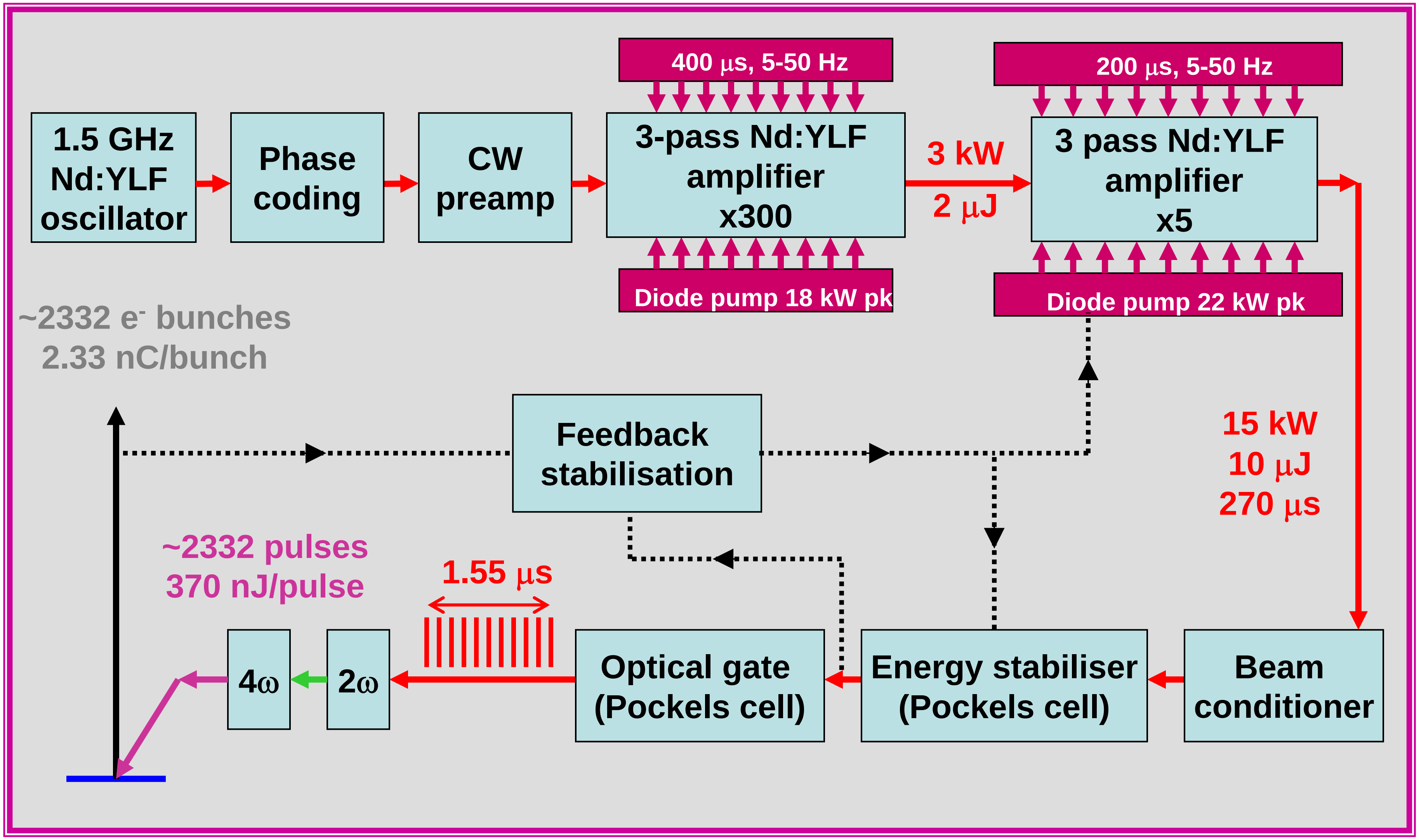
SERA

Probe Beam RF Gun

PHIN

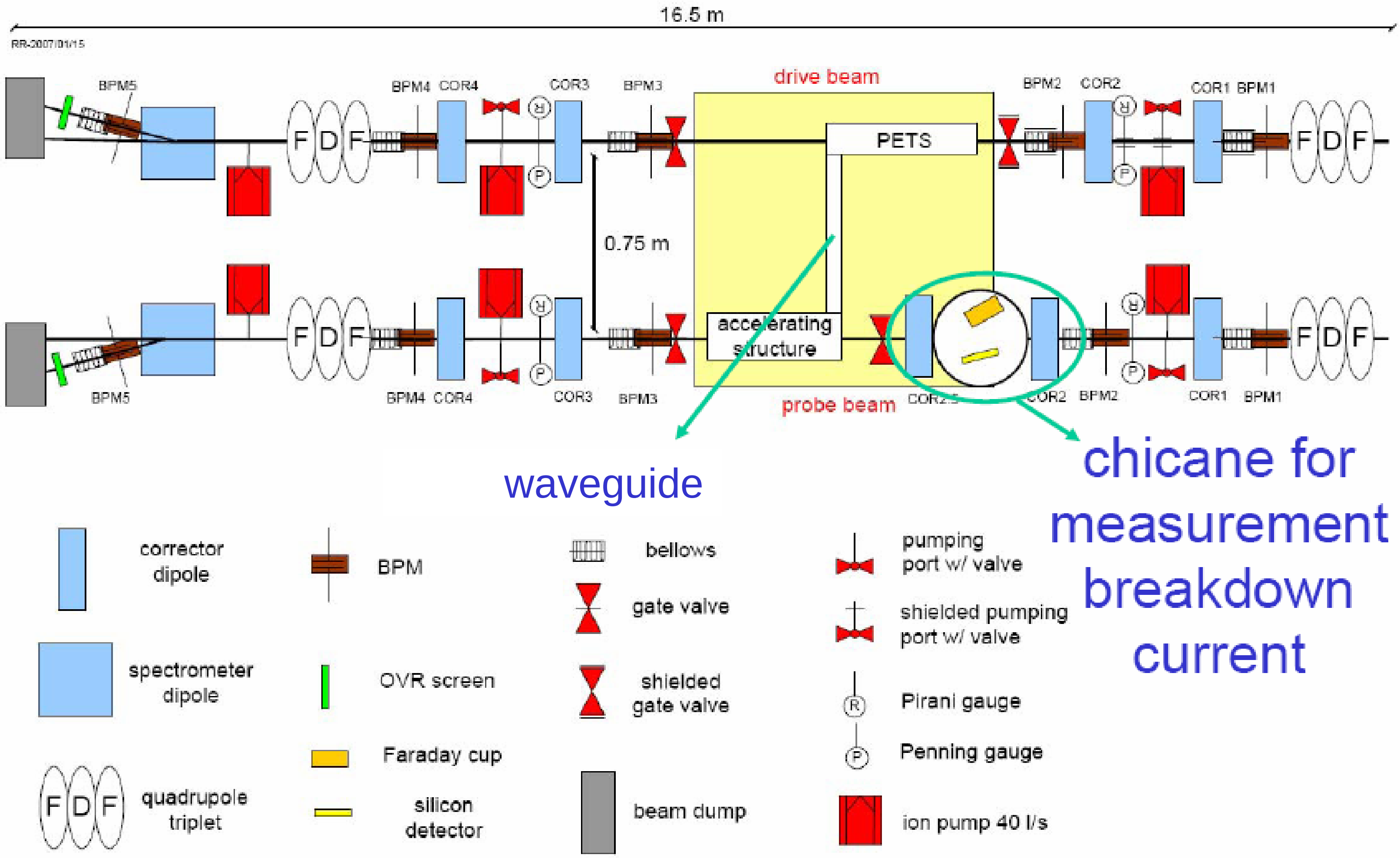


Laser system schematic



CERN installation

Two Beam Test Stand



UPPSALA UNIVERSITET

Roger Ruber
17-Jan-2007

Conclusions

- New CLIC key parameters to adapt to recent structure test results and outcomes of cost optimizations
- CTF3 installations and machine experiments on schedule for feasibility proof by 2010
- Organization of CTF3 as an international collaboration modeled after big particle physics experiment works astonishingly well !