The CLIC Linear Collider

Hans H. Braun / CERN

- Introduction CLIC & CTF3
- CTF3 status and achievements
- RF Structure tests
- Future plans and selected open issues
- Conclusions

CLIC goal

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

CLIC physics motivation

"Physics at the CLIC Multi-TeV Linear Collider :

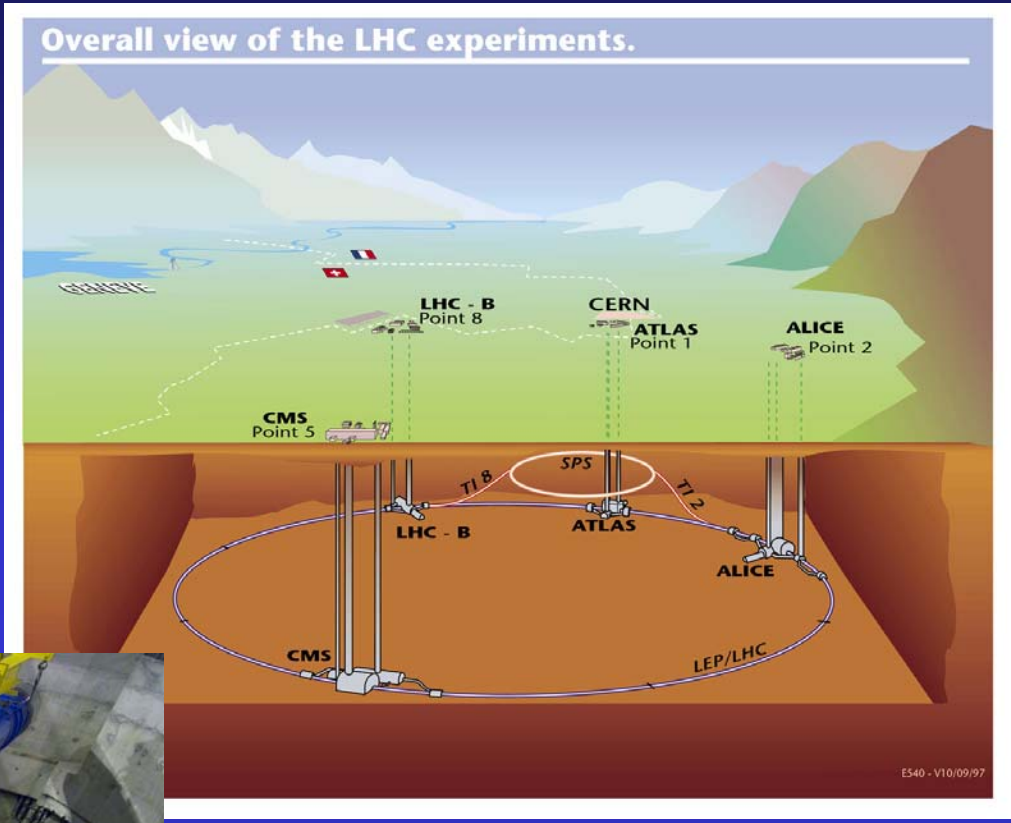
report of the CLIC Physics Working Group,"   CERN report 2004-5

Next CLIC milestone

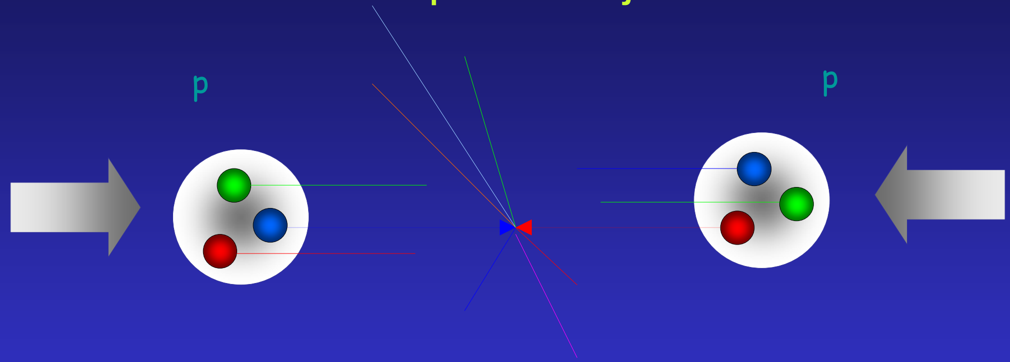
Demonstrate key feasibility issues by 2010

LHC

- Physics start-up 2008
- E_{CMS}=14 TeV proton on proton
- Very first physics analysis results from experiments expected for 2010

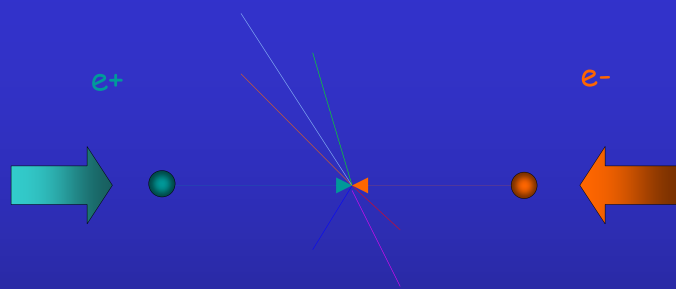


Protons are composite objects



Only fraction (≈1/6) of total proton energy available for collision of constituents

⇒ A Lepton collider

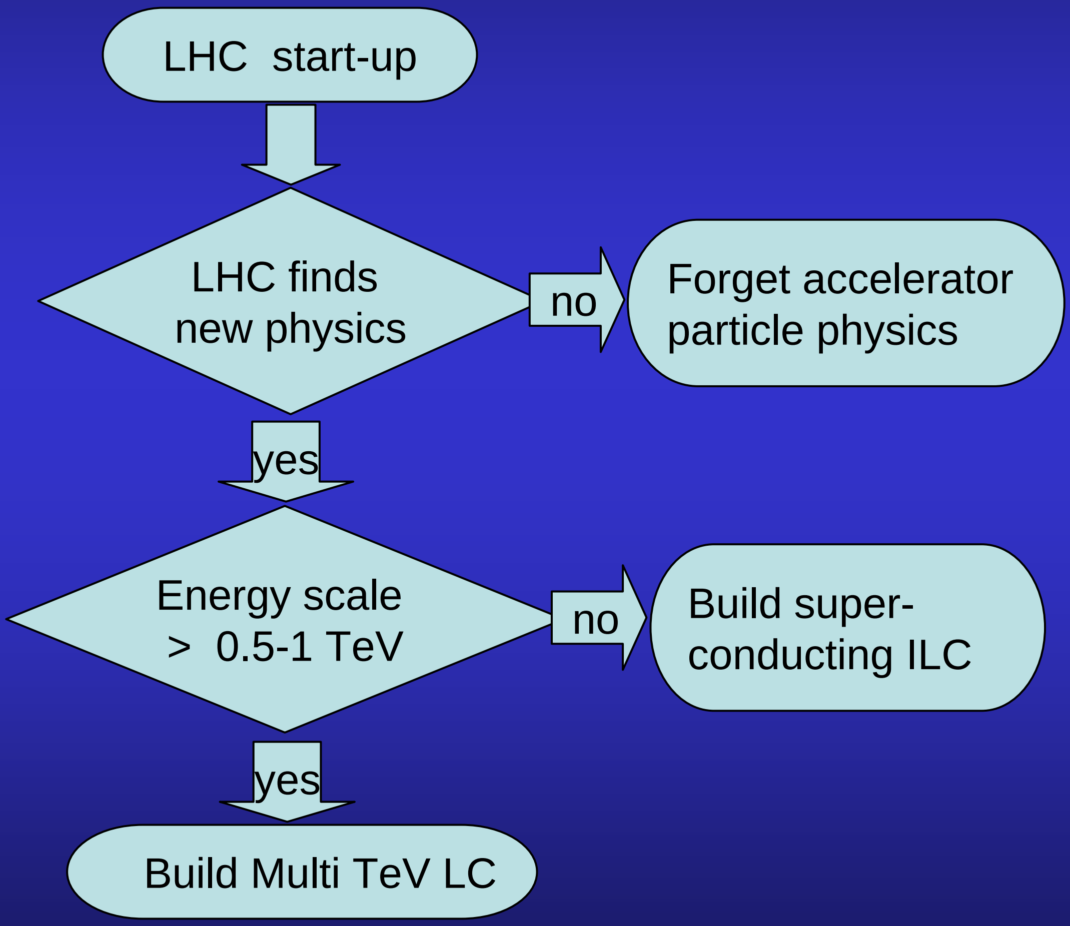


needs

$$E_{CMS} \geq 14\ \text{TeV} / 6 = 2.3\ \text{TeV}$$

to cover the energy range of LHC

My simplistic view on the future of accelerator particle physics at the energy frontier



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

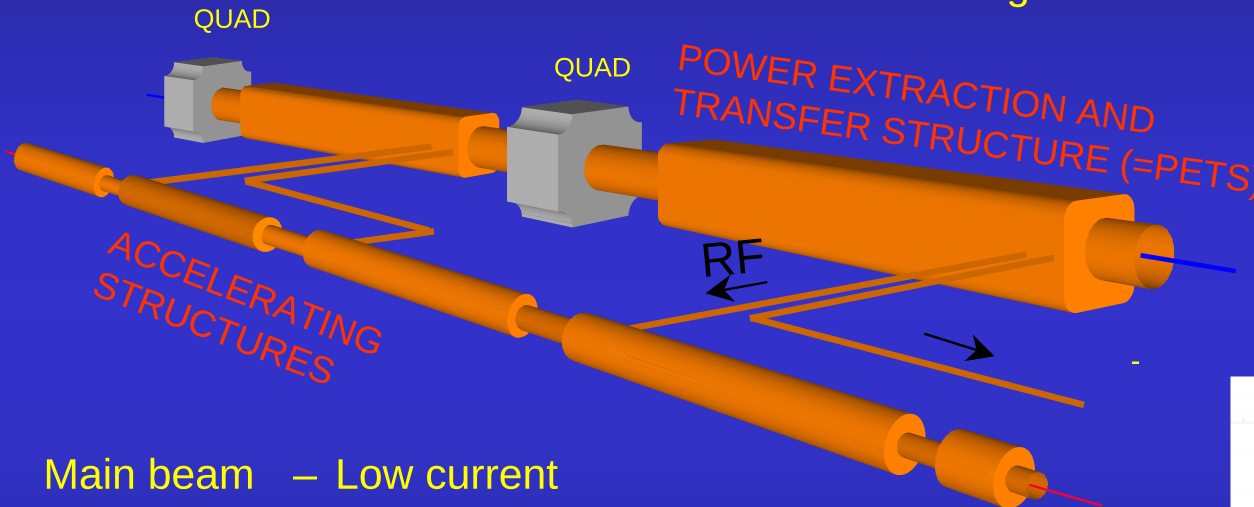
  - Cost-effective & efficient
  - Simple tunnel, no active elements

- Central injector complex

  - “Modular” design, can be built in stages

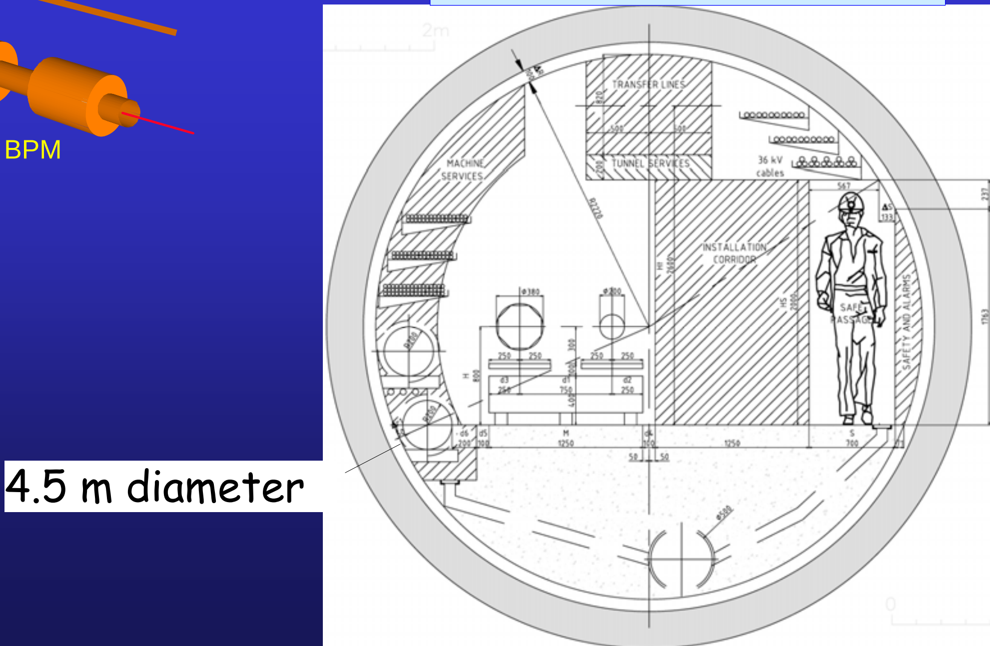
CLIC TWO-BEAM SCHEME

Drive beam - High current
- Low decelerating field



Main beam – Low current
- High accelerating field

CLIC TUNNEL CROSS-SECTION



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 ⇒ 48.3 km**

Why ?

Very promising results of earlier 30 GHz Molybdenum test structures (190 MV/m) 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

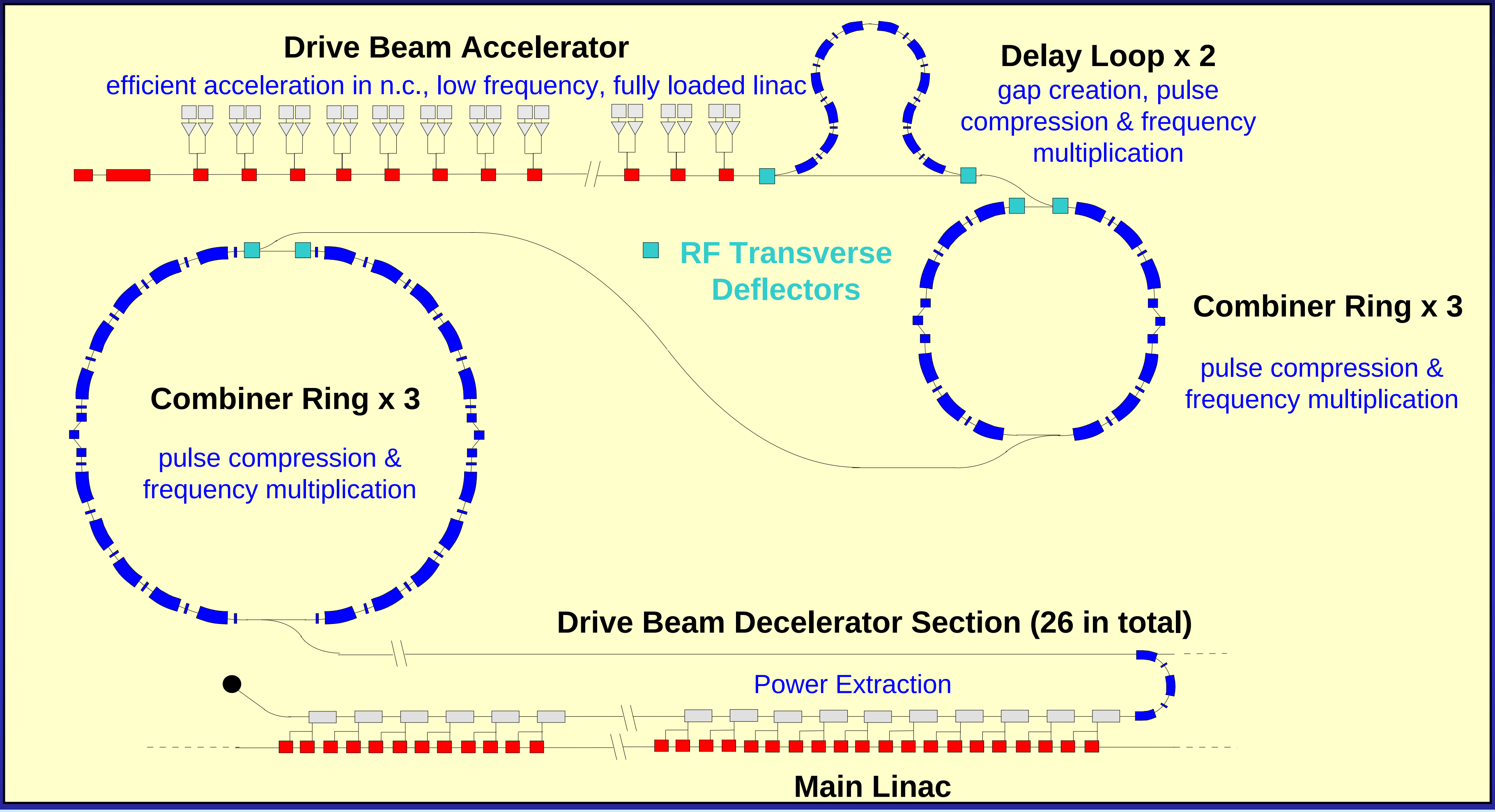
Parametric cost model indicates substantial cost savings for 12 GHz/100 MV/m
(flat minimum for this parameter range)

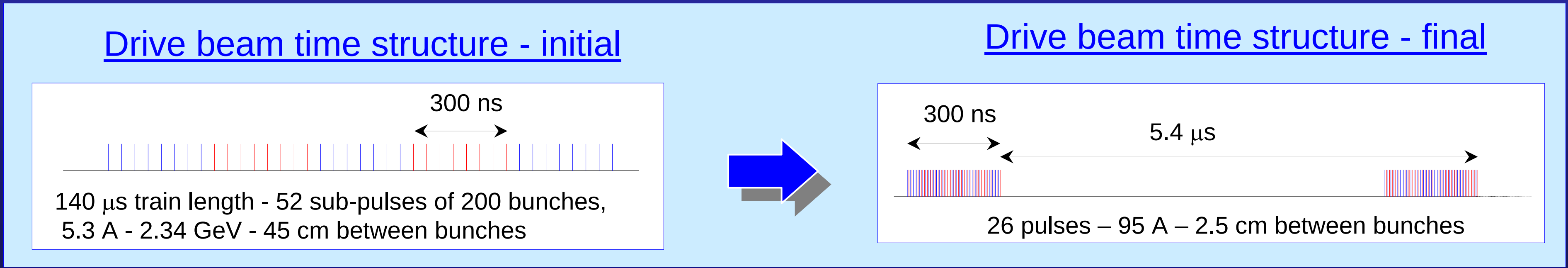
Allows RF structure testing in existing SLAC and KEK facilities

Increase chance of feasibility demonstration by 2010

100 MV/m is lowest permissible gradient for a 3 TeV machine in Geneva region

CLIC RF power source

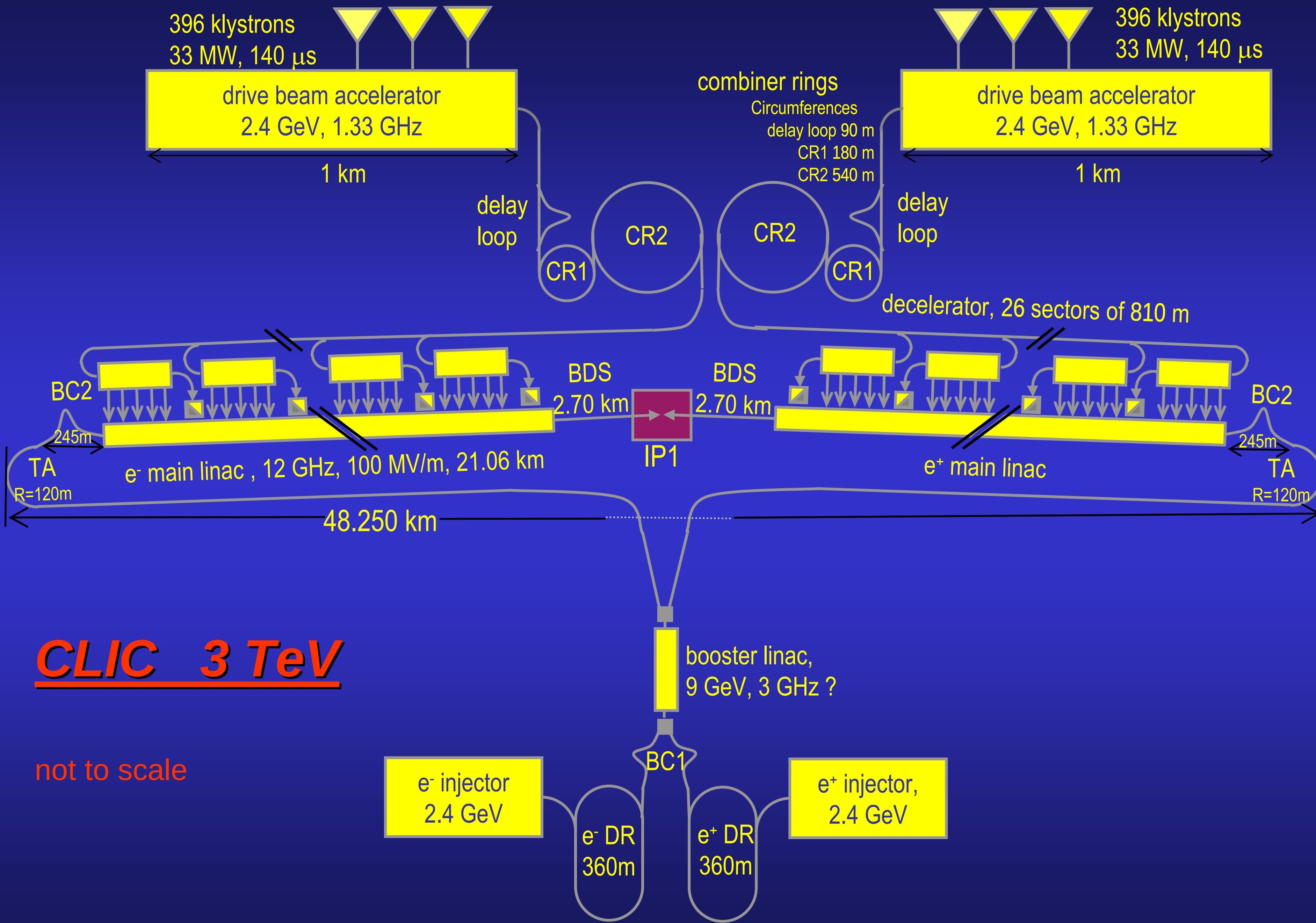




RF parameters CLIC compared with NLC

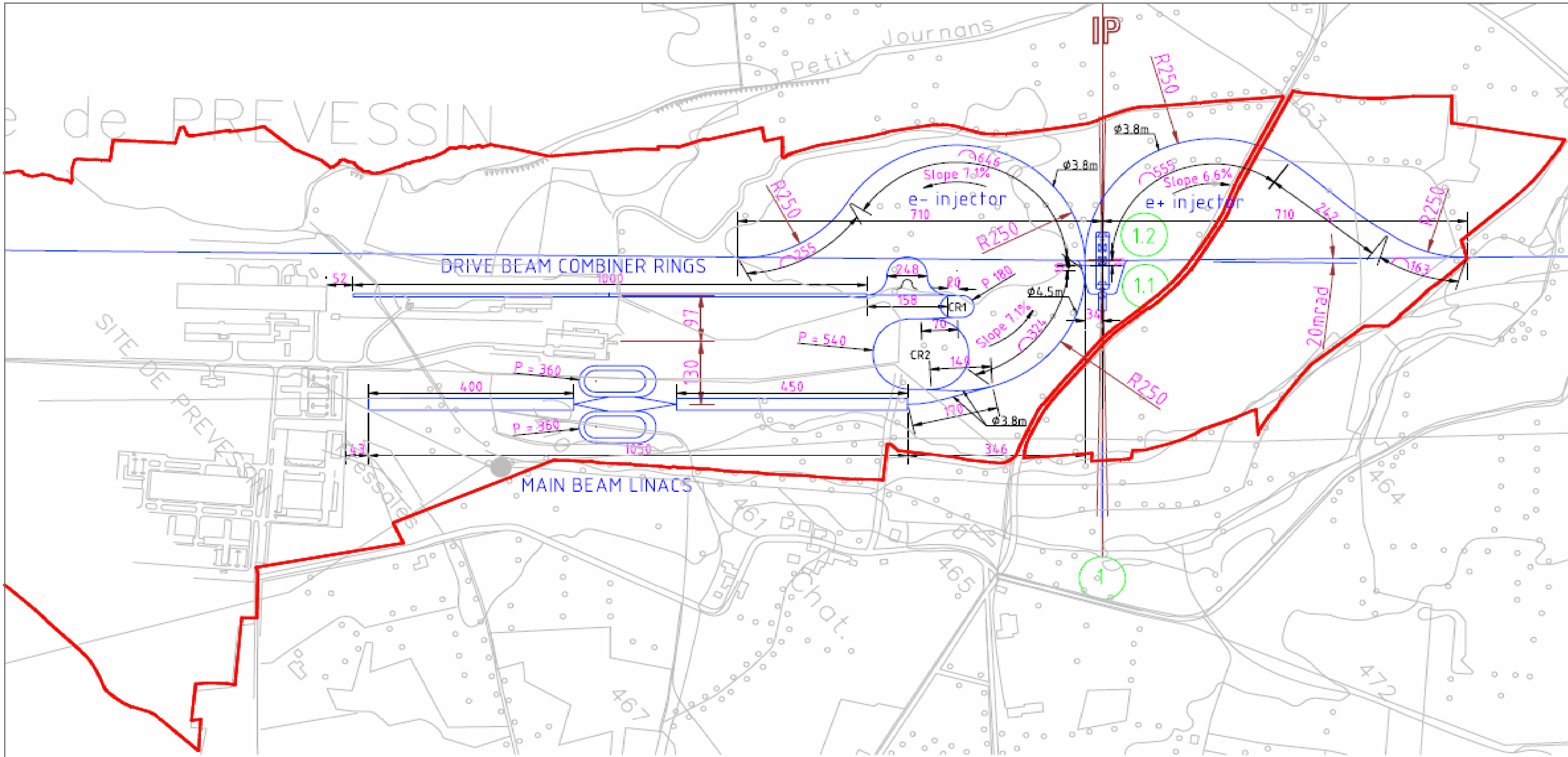
		CLIC **12 GHz, 100 MV/m** *preliminary*	**NLC** *as for ILC-TRC 03*
Loaded Accelerating Gradient	MV/m	100	50
Frequency	GHz	12	11.4
Structure iris aperture radius a/λ	1	0.155-0.0852	0.21-0.148
Structure length	mm	229	900
Structure input power	MW	76	75
Pulse length	ns	300	400
Bunch charge	$e_0 x10^9$	5.2	7.5
Bunch separation	rf cycles	8	16
Beam current	A	1.25	0.86
RF to beam efficiency	%	28.8	31.5
Rep. rate	Hz	50	120
No. Klystrons per TeV	1	264	8256
Klystron frequency	GHz	1.33	11.4
Klystron peak power	MW	33	75
Klystron RF pulse length	μs	140	1.6
Average power per klystron	kW	231	14.4

CLIC 3 TeV



not to scale

Main/Drive Beam Injectors and Experimental Area Layout



connections to common transfer tunnel (Ø 3.8m)

e- e+ beam tunnel = 170 m

drive beam tunnel = 140 m

common transfer tunnel (Ø 4.5m)

324 + 10 = 334m

final transfer tunnels (Ø 3.8m)

e- beam tunnel = 901 m

e+ beam tunnel = 971 m

CLIC- MAIN / DRIVE BEAM INJECTORS AND EXPERIMENTAL AREA LAYOUT

CERN | GROUP : TS-CE CIVIL ENGINEERING SUPERVISOR : JL.BALDY DESIGNER : N.BADDAMS | SCALE : 1/6500(A3_FORMAT) DATE : 07_MAI_2007 | CLIC.CE-1.1799.0002 | SIZE 3 | INDICE -

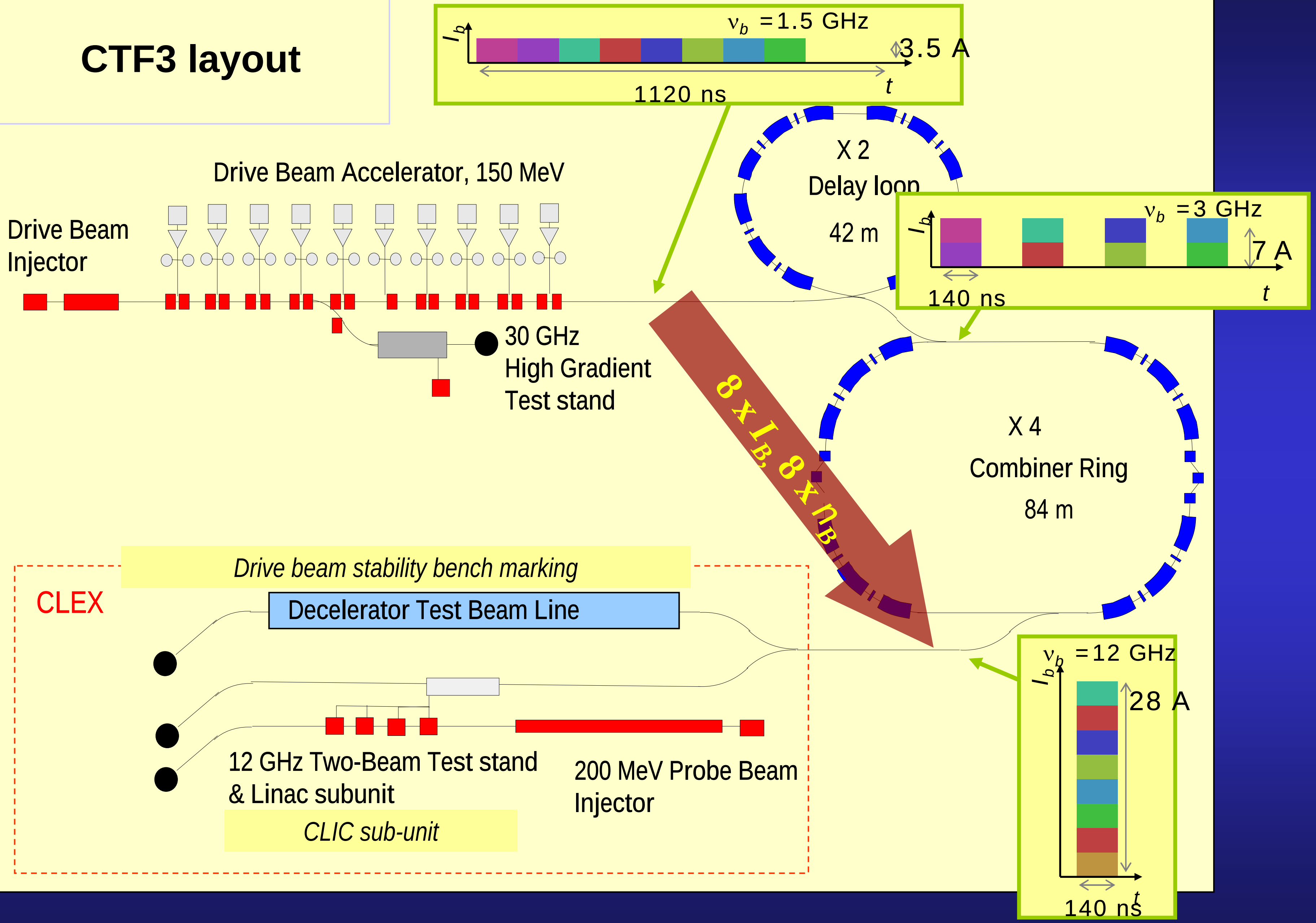
Motivation and Goals of CTF3 collaboration

- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - High efficiency 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

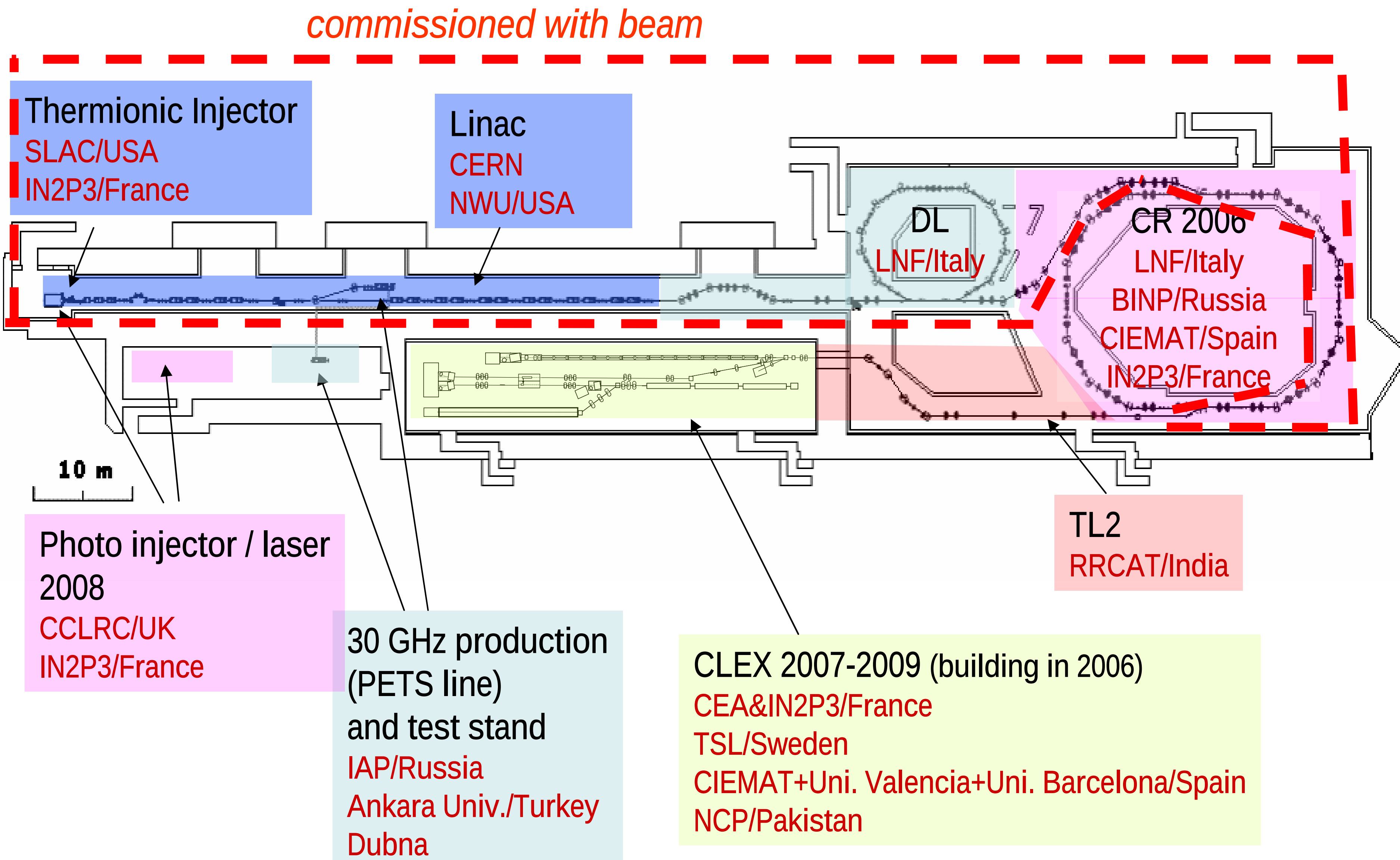
- ***Tool to demonstrate until 2010 CLIC feasibility issues identified by ILC-TRC in 2003***

CTF3 layout



ν_b =1.5 GHz
I_b
3.5 A
1120 ns
t
X 2
Delay loop
42 m
ν_b =3 GHz
I_b
7 A
140 ns
t
Drive Beam Accelerator, 150 MeV
Drive Beam
Injector
30 GHz
High Gradient
Test stand
8 x I_B, 8 x ν_B
X 4
Combiner Ring
84 m
ν_b =12 GHz
I_b
28 A
140 ns
t
Drive beam stability bench marking
CLEX
Decelerator Test Beam Line
12 GHz Two-Beam Test stand
& Linac subunit
CLIC sub-unit
200 MeV Probe Beam
Injector

CTF3 build by a collaboration like a particle physics experiment



CTF3 collaboration
official members

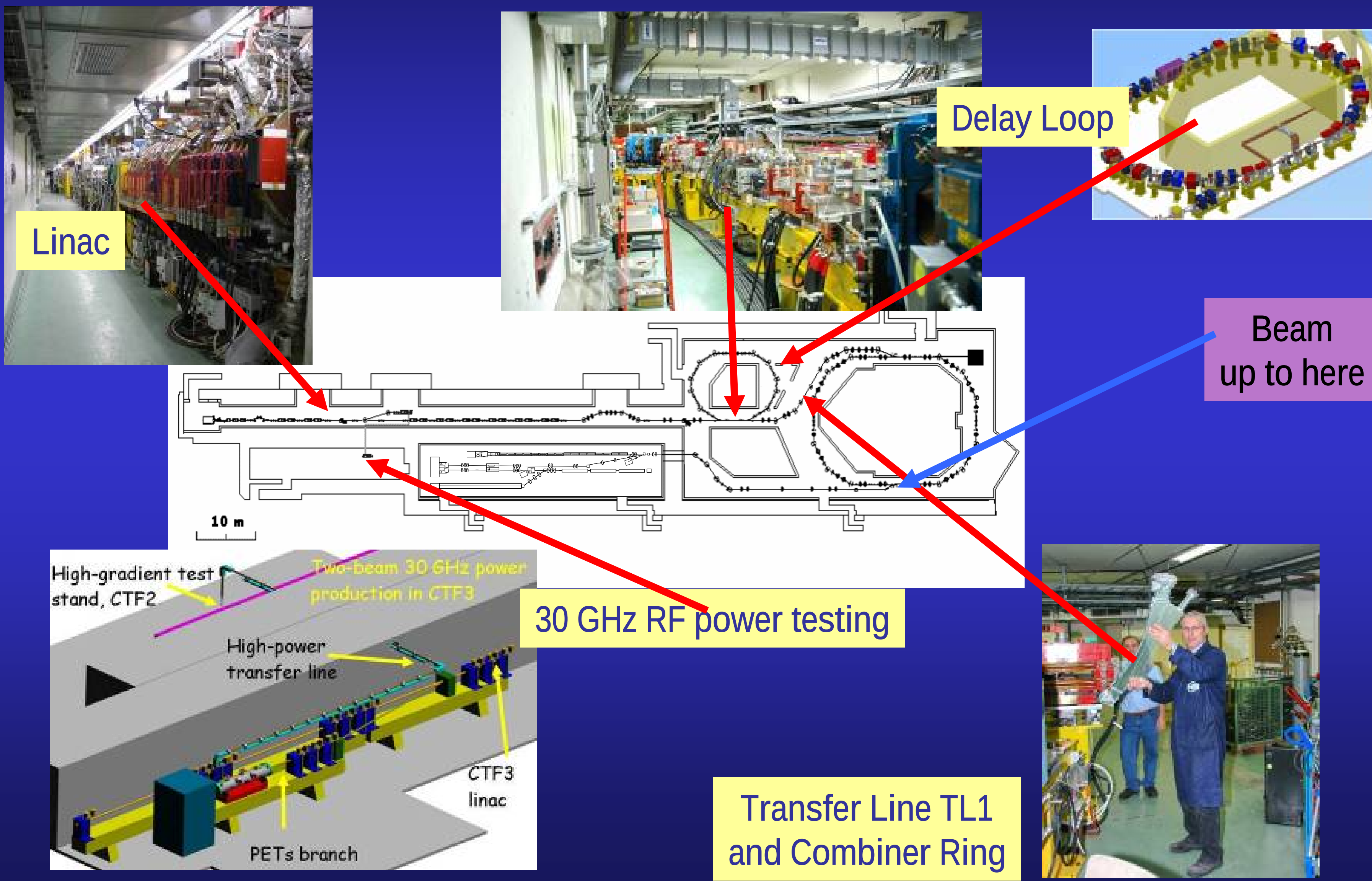
Country	Institute
20 member states	CERN
Finland	Helsinki Inst. of Physics
France	DAPNIA
	LAL
	LAPP
India	BARC
	RRCAT
Italy	LNF
Pakistan	NCP
Russia	BINP
	IAP
	JINR
Spain	CIEMAT
	IFIC
	UPC
Sweden	Uppsala University
Switzerland	PSI
Turkey	Ankara Universities
USA	NWU
	SLAC

collaboration board

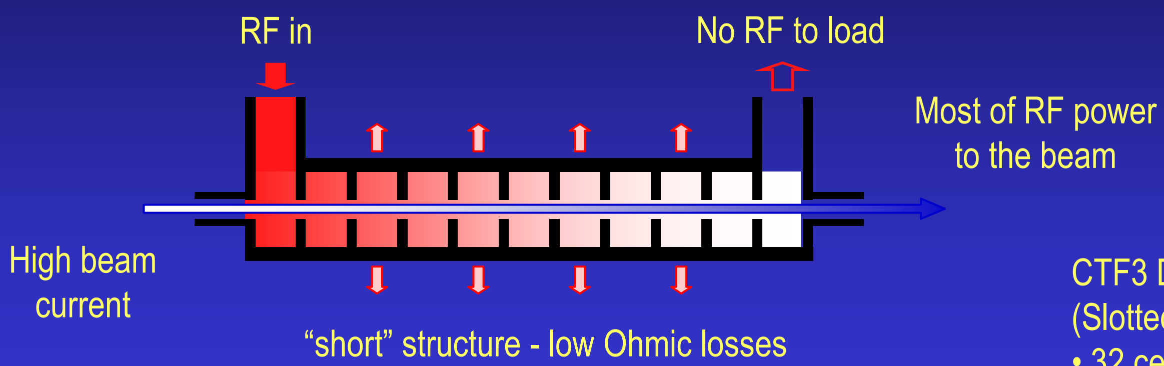
chairman
M. Calvetti / LNF

spokesperson
G. Geschonke / CERN

Some impressions from CTF3



Fully beam loading operation in CTF3



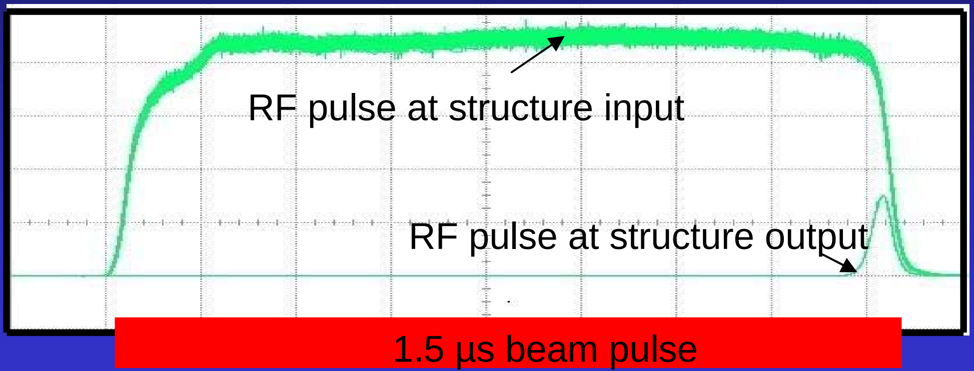
theoretical RF-to-beam efficiency: 96%

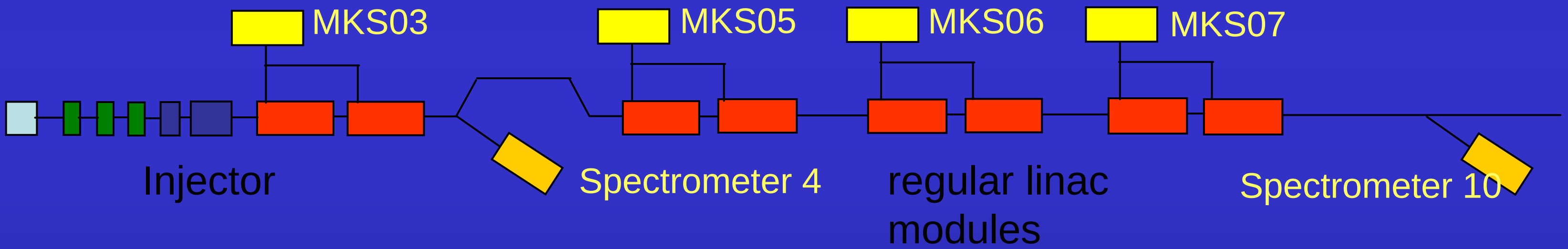
CTF3 Drive Beam Acc. Structures (3 GHz) – SICA (Slotted Iris – Constant Aperture):

- 32 cells
- 1.2 m long
- 2π/3 mode
- 6.5 MV/m av. acc. gradient for 3.5 A beam current
- HOM damping slots

Full beam loading operation in CTF3 – Demonstration for CLIC operation

Setup: Adjust RF power and phase and beam current, that fully loaded condition is fulfilled



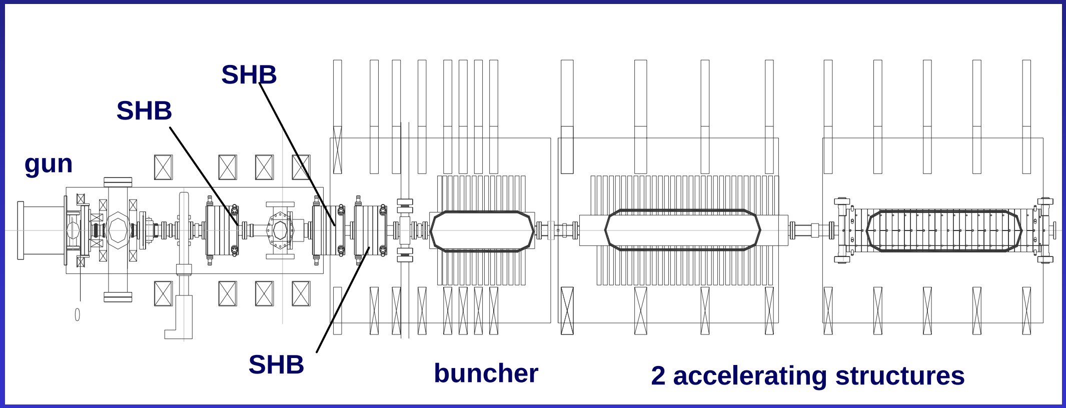


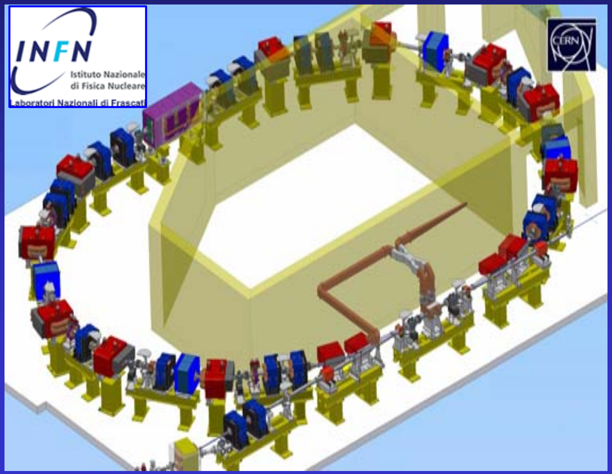
Precise measurement of
- **beam current,**
- **beam energy in spectro 4 and spectro 10**
- **RF structure input power**

Measured RF-to-beam efficiency: 95.3 %
Theory: 96% (~4 % ohmic losses)

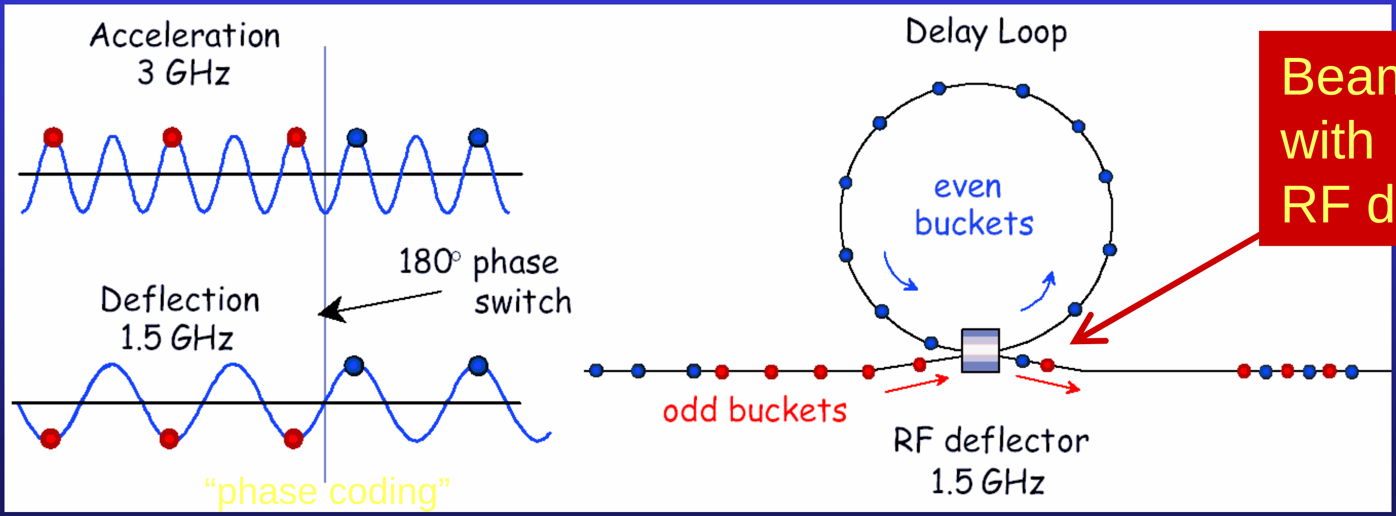
How does the bunch frequency multiplication work?

CTF3 Injector with 3 SHB cavities (1.5 GHz)





Phase coding and bunch frequency multiplication in delay loop



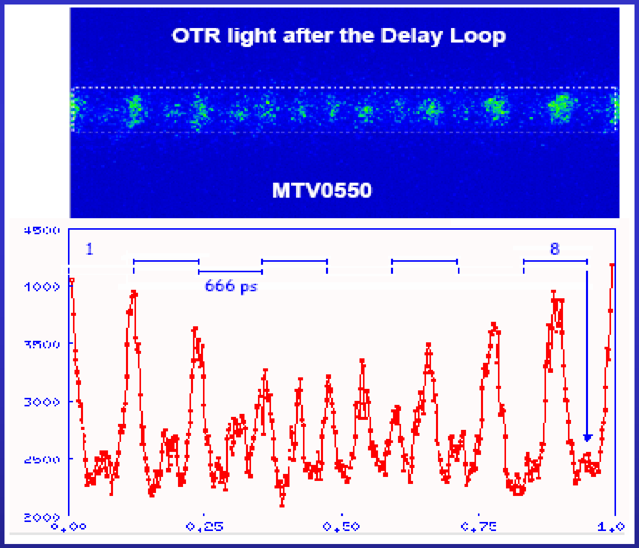
Beam combination with transverse RF deflector

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)

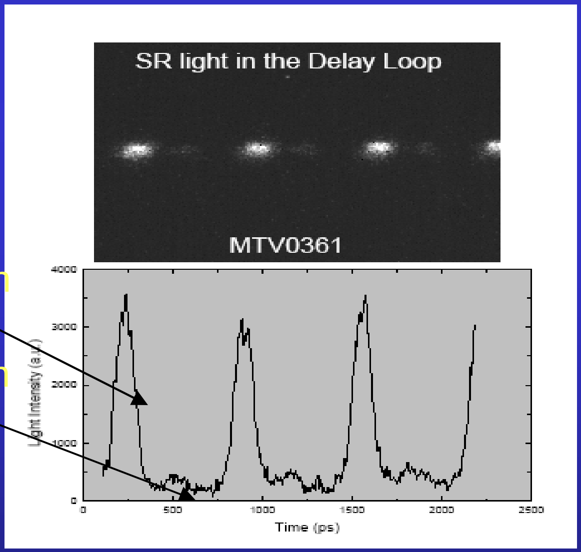
phase switch:

satellite bunch population:



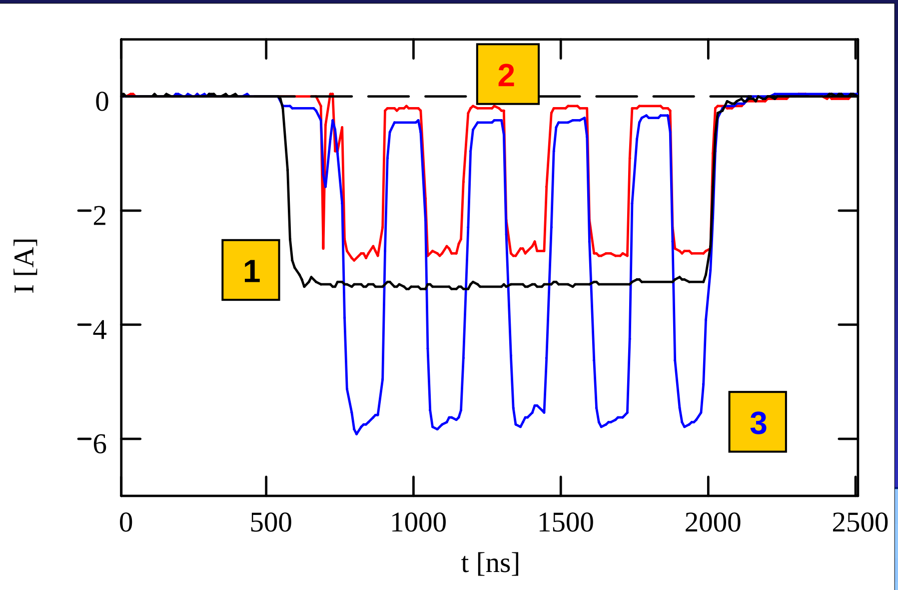
main bunch

satellite bunch

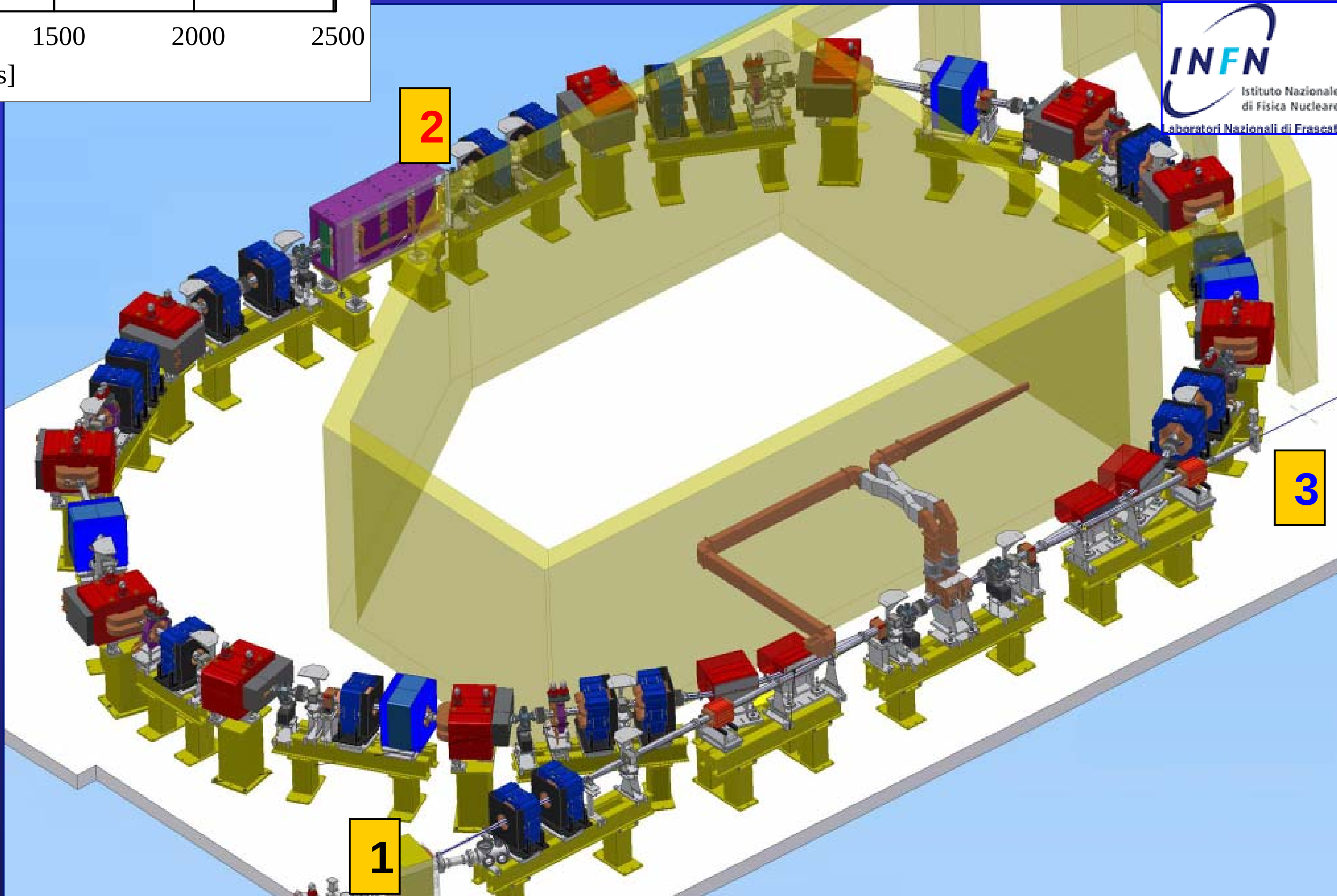


Phase switch is done within eight 1.5 GHz periods **(<6 ns).**

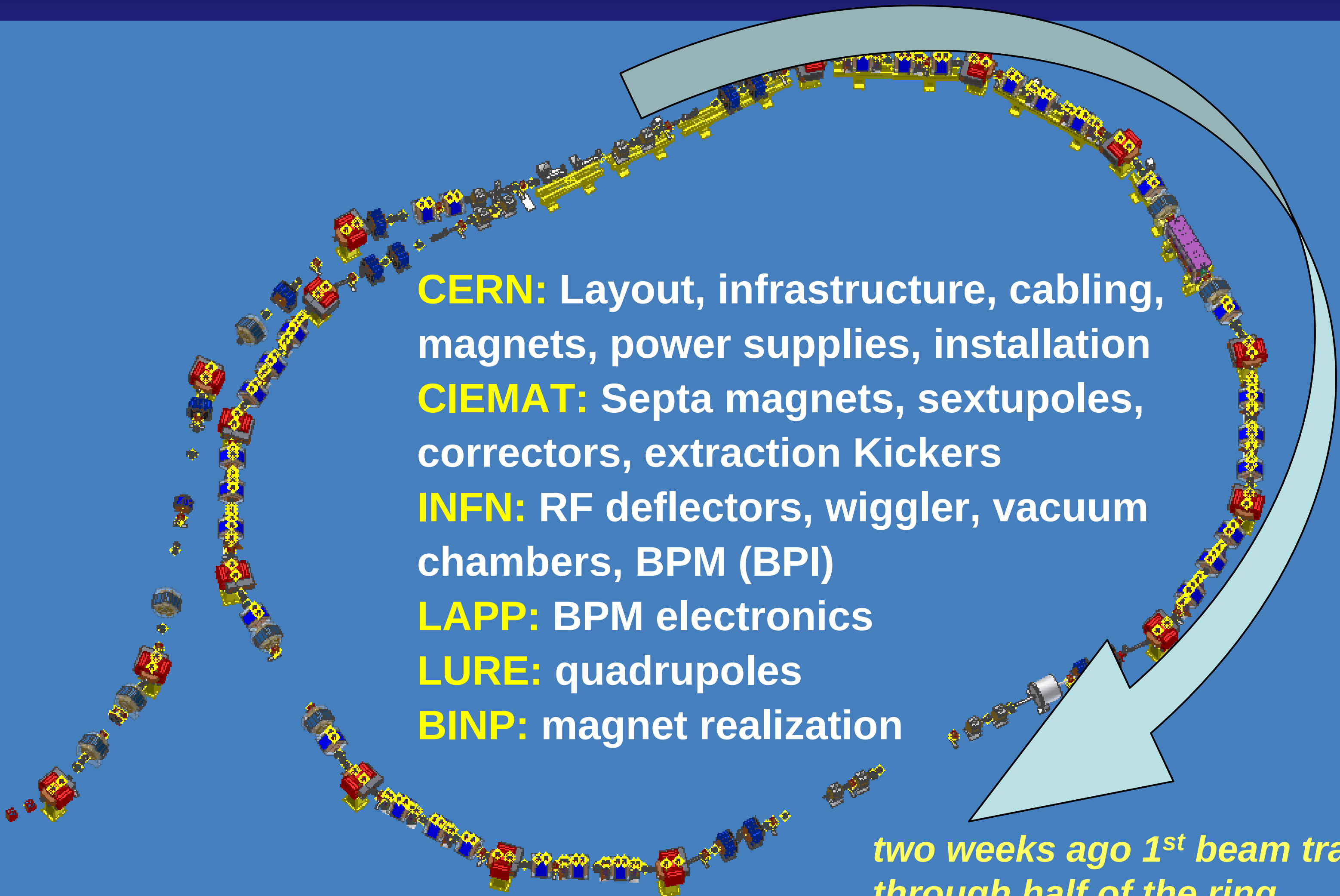
Satellite bunch population was estimated to **~8 %.**



Beam recombination in the Delay Loop (factor 2)



Present CTF3 run: Combiner Ring commissioning
Status: half way round



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

two weeks ago 1st beam transport through half of the ring, from injection to extraction

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.

CLIC Accelerating structure test facilities

Operational

- 30 GHz structures, CTF3 linac test stand
  (no commercial high power power source at this frequency)

- 12 GHz structures. Klystrons of SLAC-NLCTA (actually at 11.4 GHz)

Future plans

- From 2009 12 GHz test capabilites in CTF3 CLEX two beam test stand TBTS
  will also test the decelerator prototype for the drive beam decelerator

- Testing at KEK facilities ?

- A 12 GHz klystron based test stand at CERN for late 2009 is presently
  under discussion in collaboration with several European FEL projects
  who intend to use X-band acceleration.

Some remarks about CLIC parameter change and CTF3

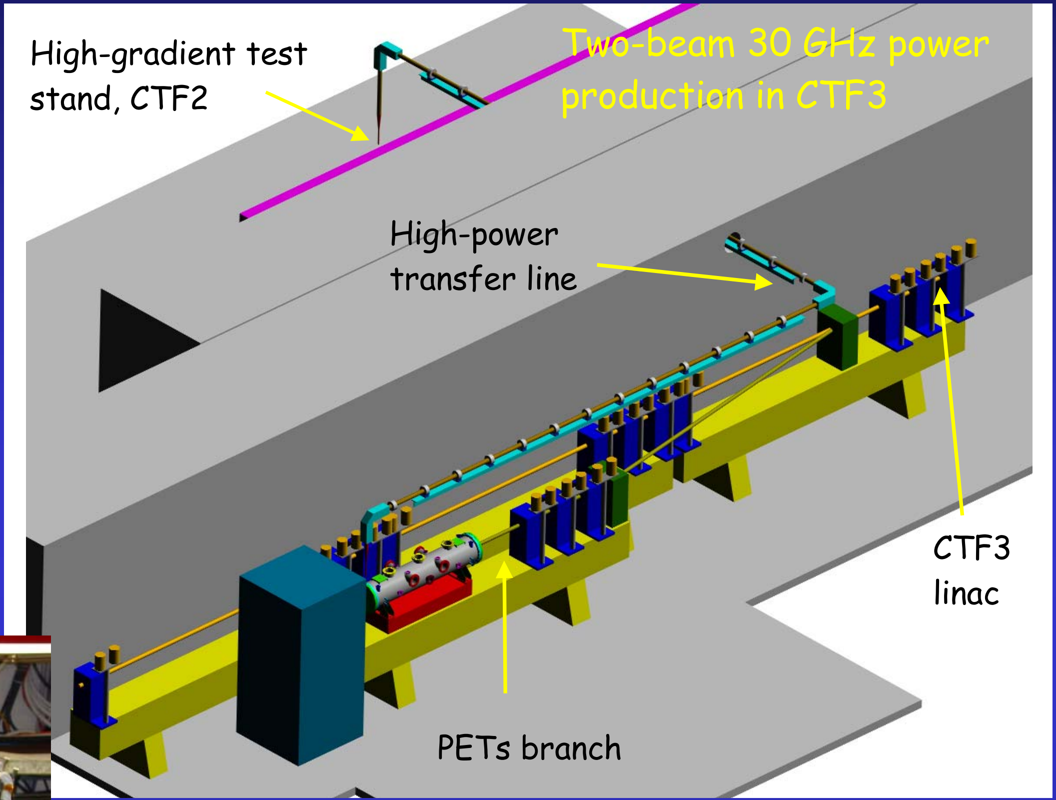
Bunch repetition frequency of drive beam can be readily chosen as 6, 9, 12, 15 GHz by varying number of stacking turns in combiner ring and fine tuning of ring circumference with wiggler.
Drive beam can produce RF on any harmonic of these frequencies.
This makes adaptation of CTF3 drive beam to new frequency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

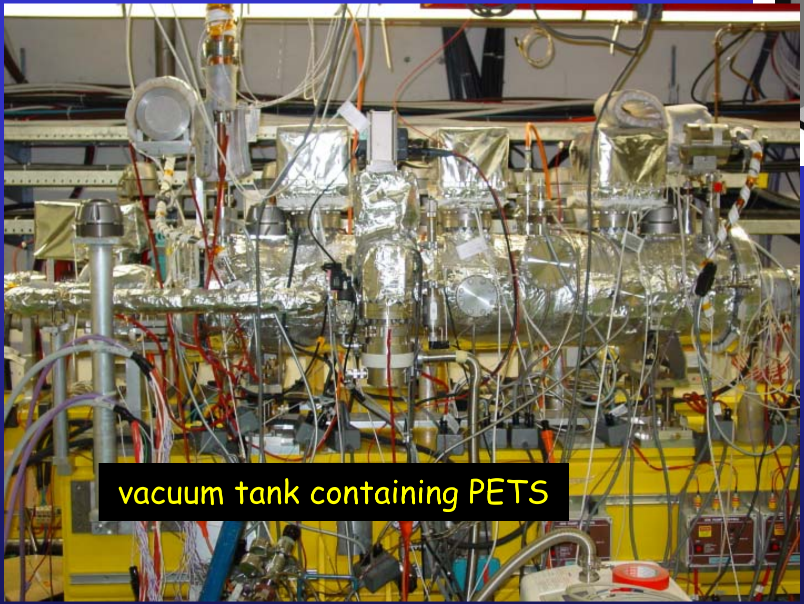
Definitive frequency choice was urgent, since ordering of RF components for CLEX two beam test has to start now.

30 GHz RF source in CTF3

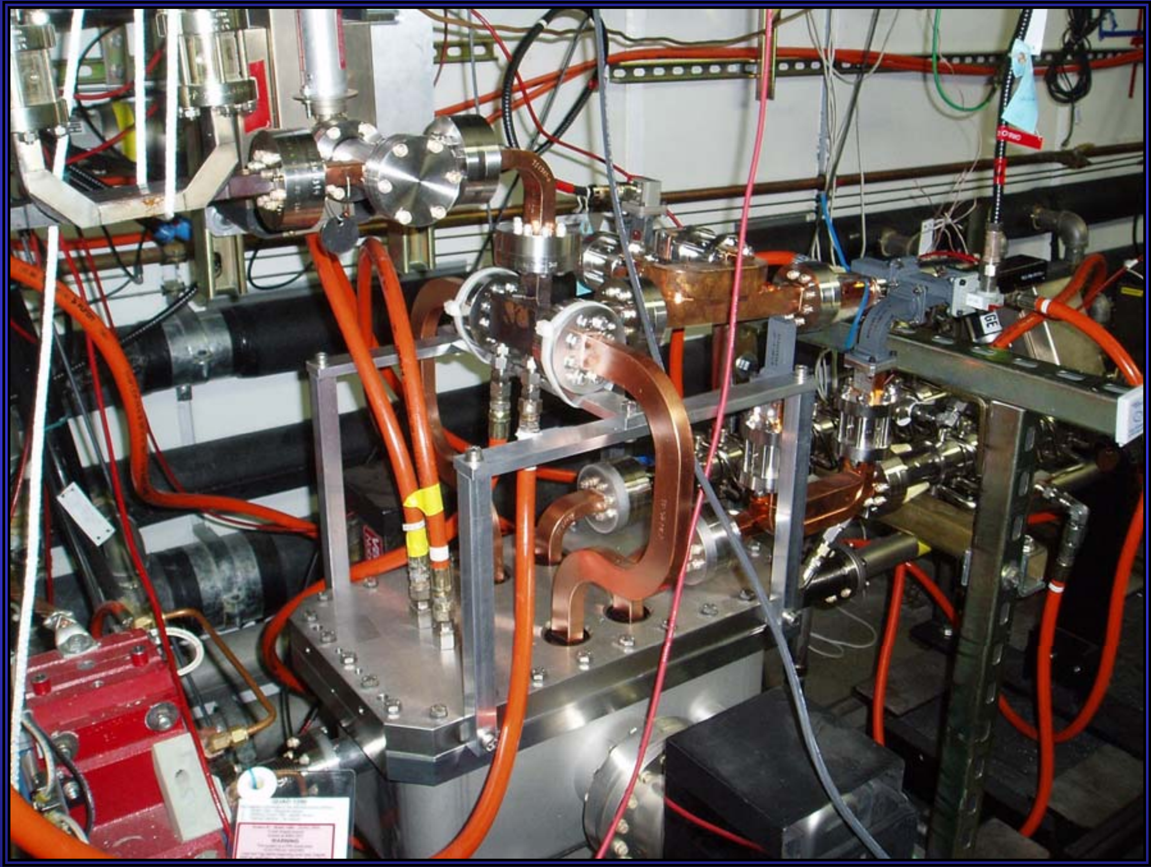
CTF3 linac beam at mid linac point
I_{beam}=5 A, T=90 MeV is decelerated
in PETS (=power extraction and transfer structure)

70 MW, 400 ns, 1-50 Hz available for structure testing

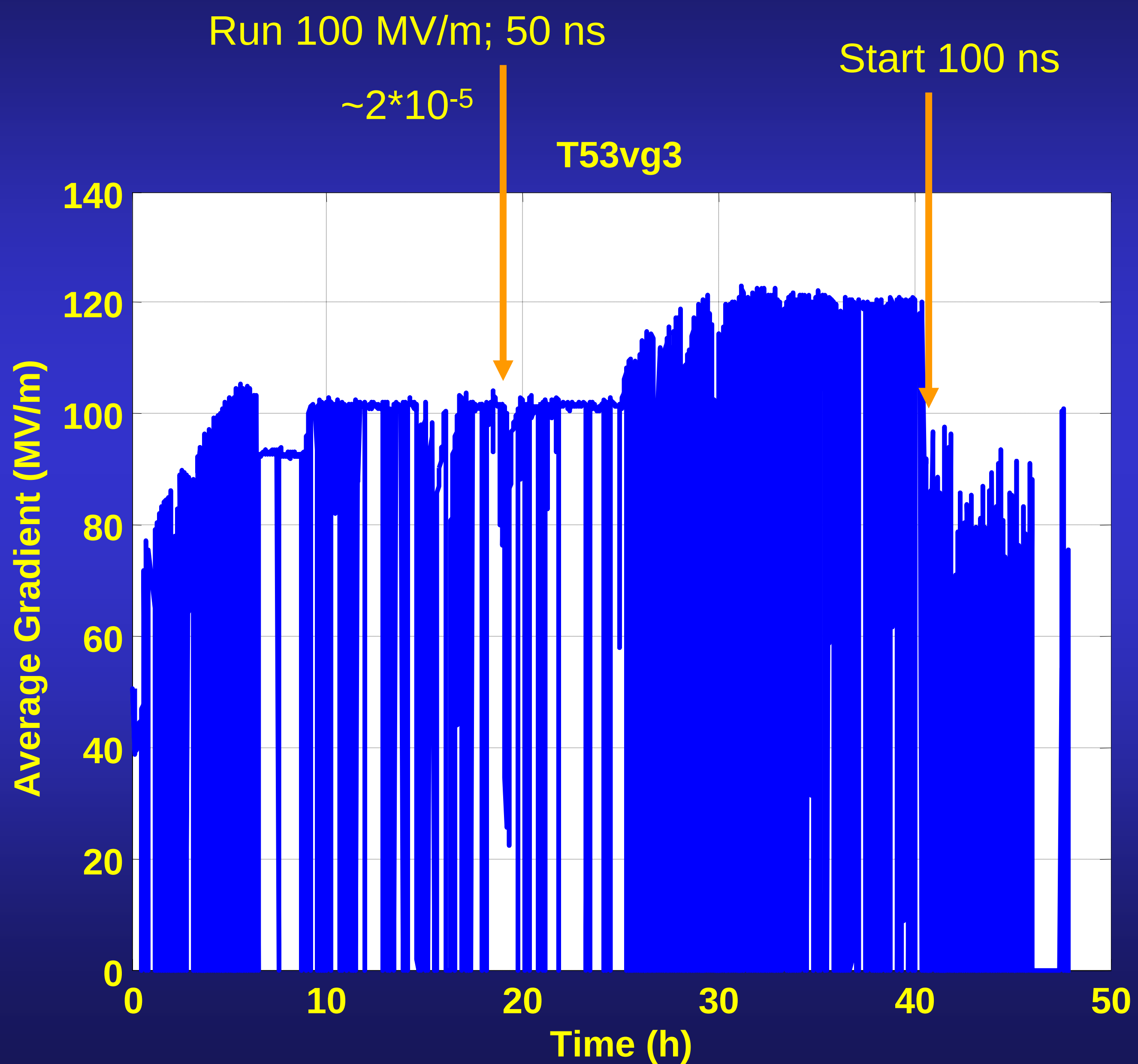


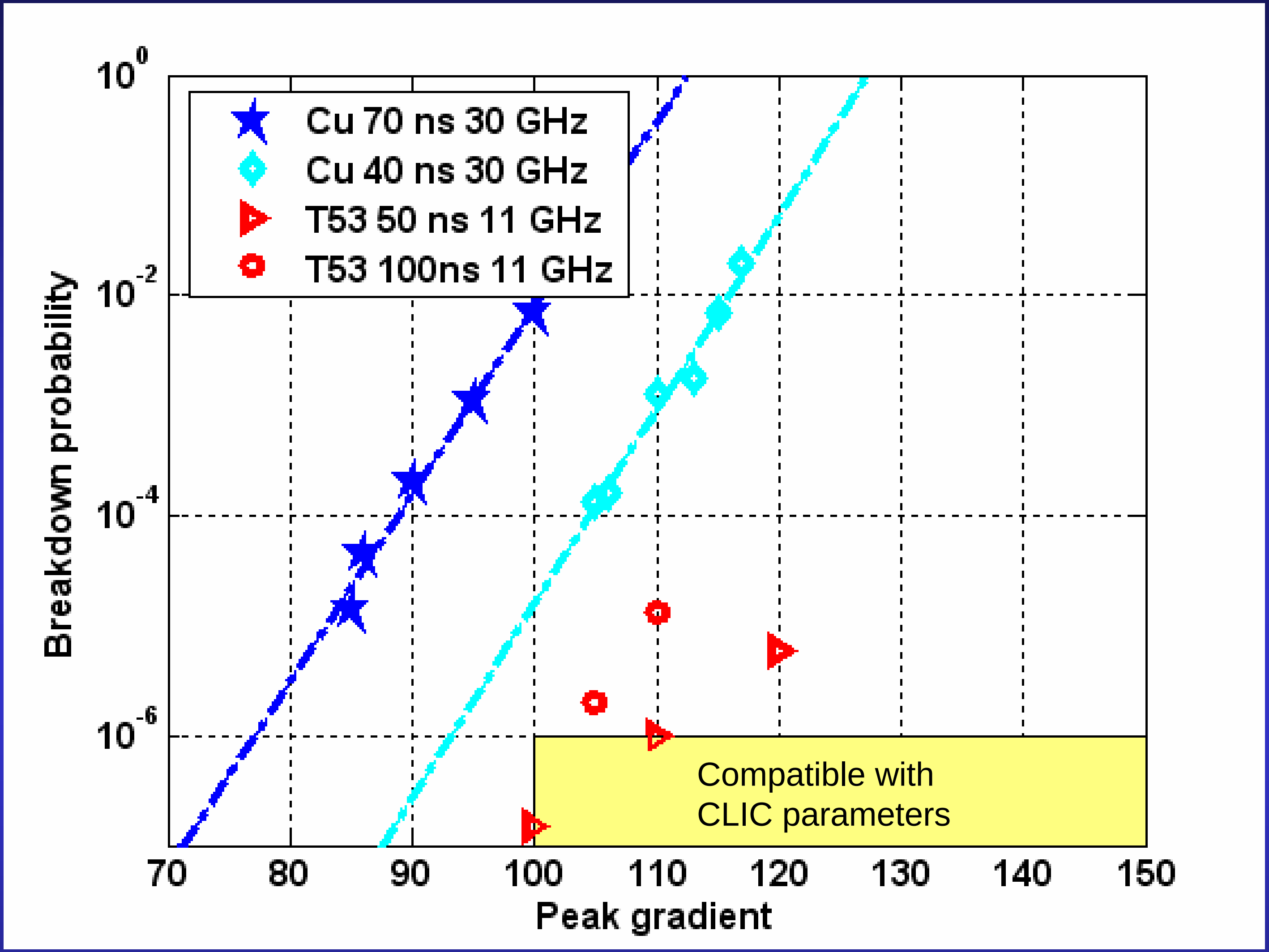


Present RF power test of CLIC 12 GHz (actually 11.4 GHz) prototype structure at NLCTA (SLAC)



RF conditioning curve of presently ongoing test at SLAC-NLCTA of existing SLAC NLC 11.4 GHz prototype “T53vg3” with CLIC type parameters

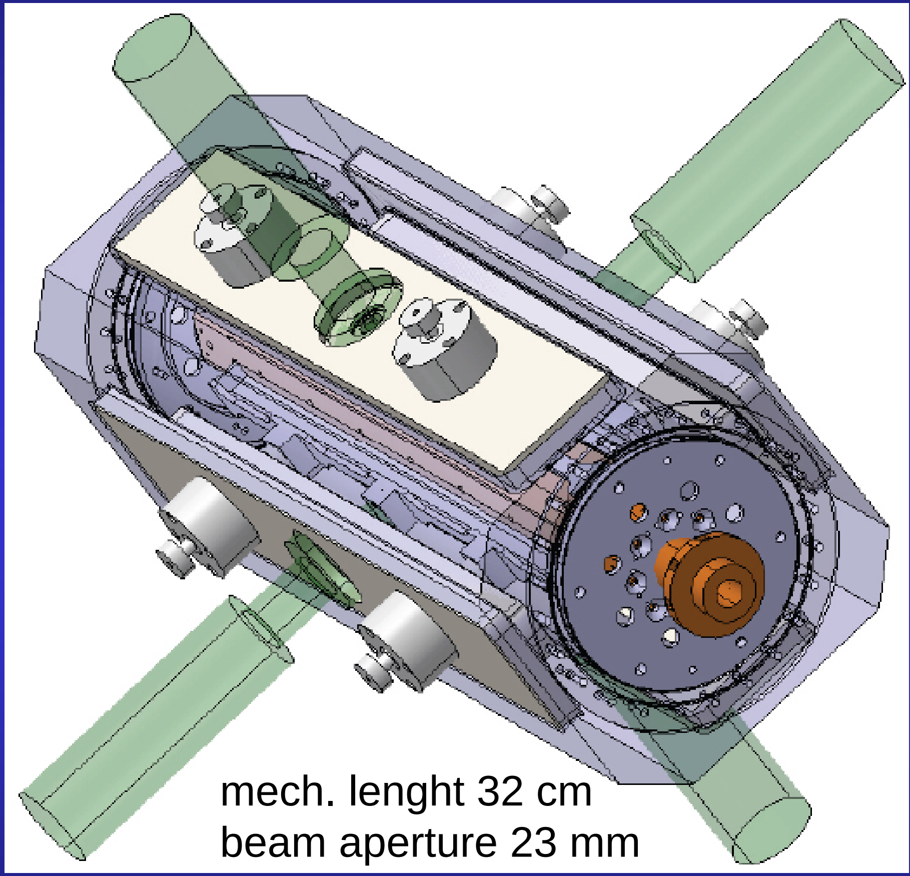


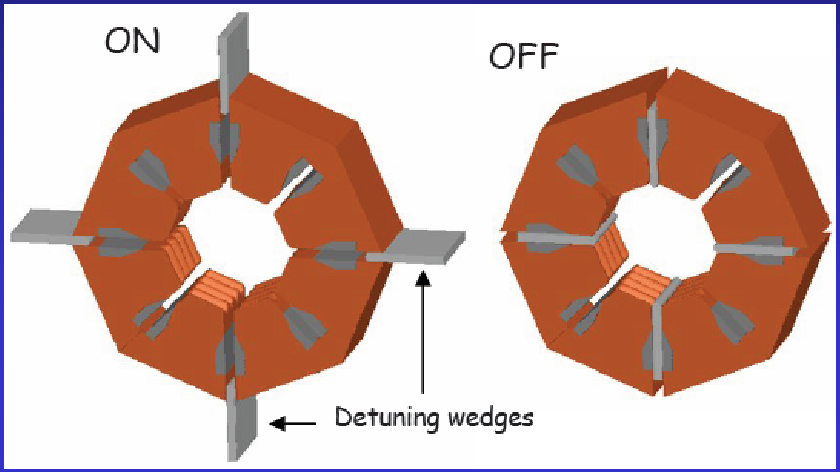


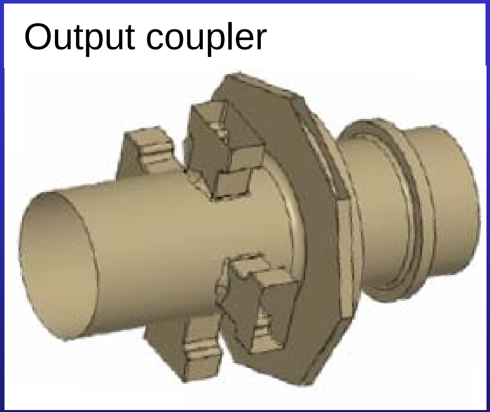
To achieve 300 ns pulse length at 100 MV/m still a lot of progress required.
Improvements expected from new shorter structures with less peak power flow.
Alternatively pulse length can be reduced at expense of power efficiency.

Power extraction and transfer structure PETS

Extracts 140 MW of power from 95 A drive beam
to feed two main beam accelerating strucutres







Will be tested in CTF3 two beam test stand from late 2008 on

Functionality and Specifications for TL2 (commissioning spring 2008)

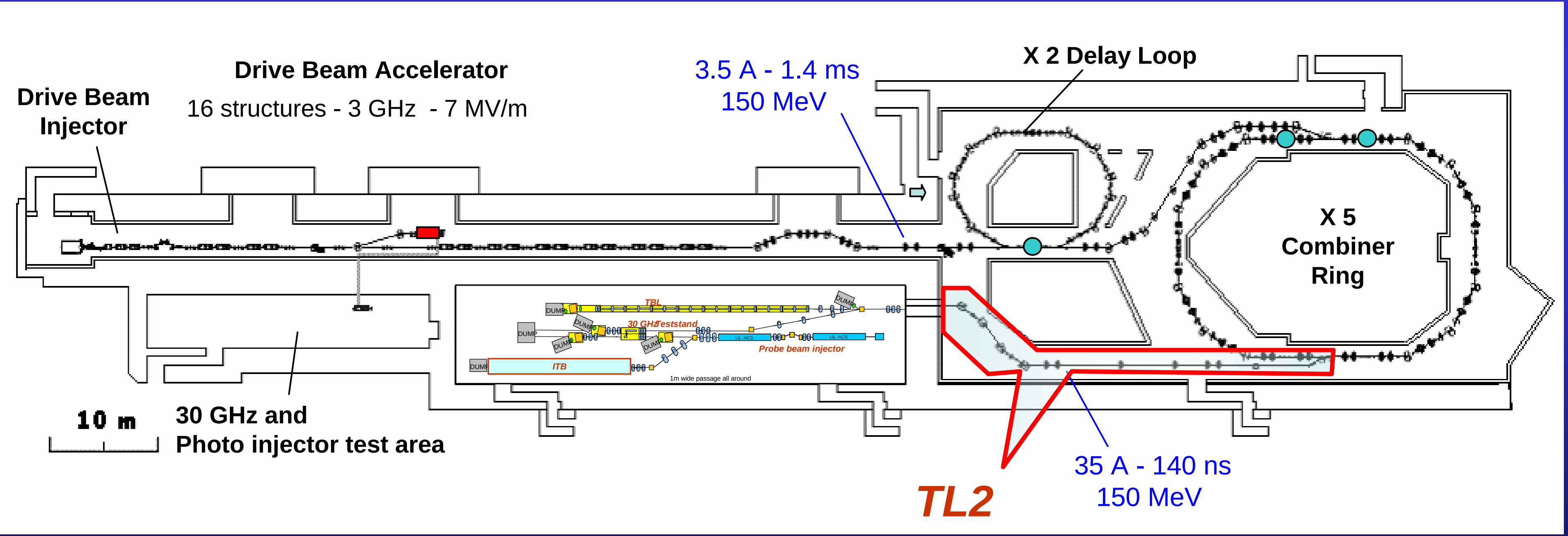
Transport of drive beam from combiner ring extraction to CLEX

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

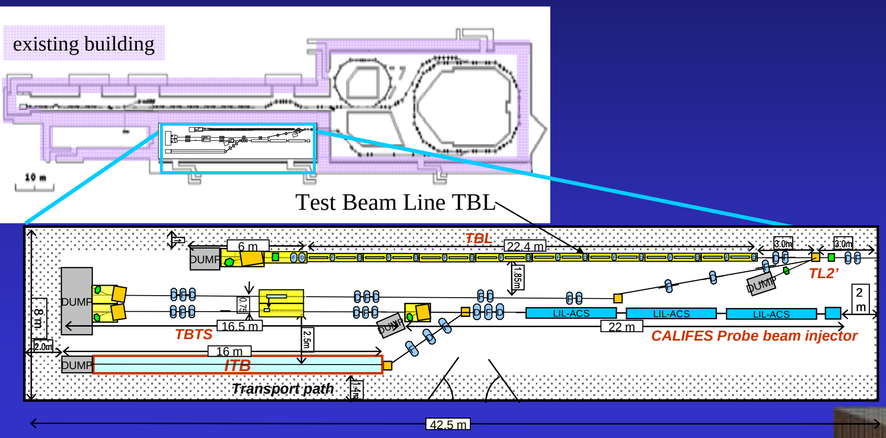
Emittance dilution < 10% (for 150 MeV, $e_{x,y}$=100 mm)

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



CLEX building



Construction on schedule
Equipment installation starts this month (May 2007)
First beam to CLEX in spring 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

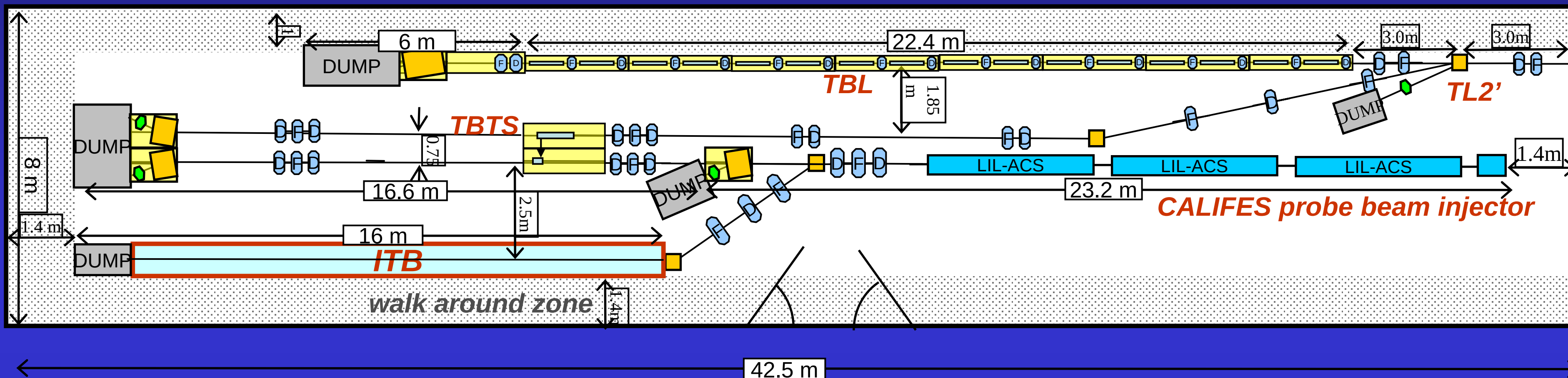
TBL=Test Beam Line
Feasibility demonstration of CLIC drive beam decelerator

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**

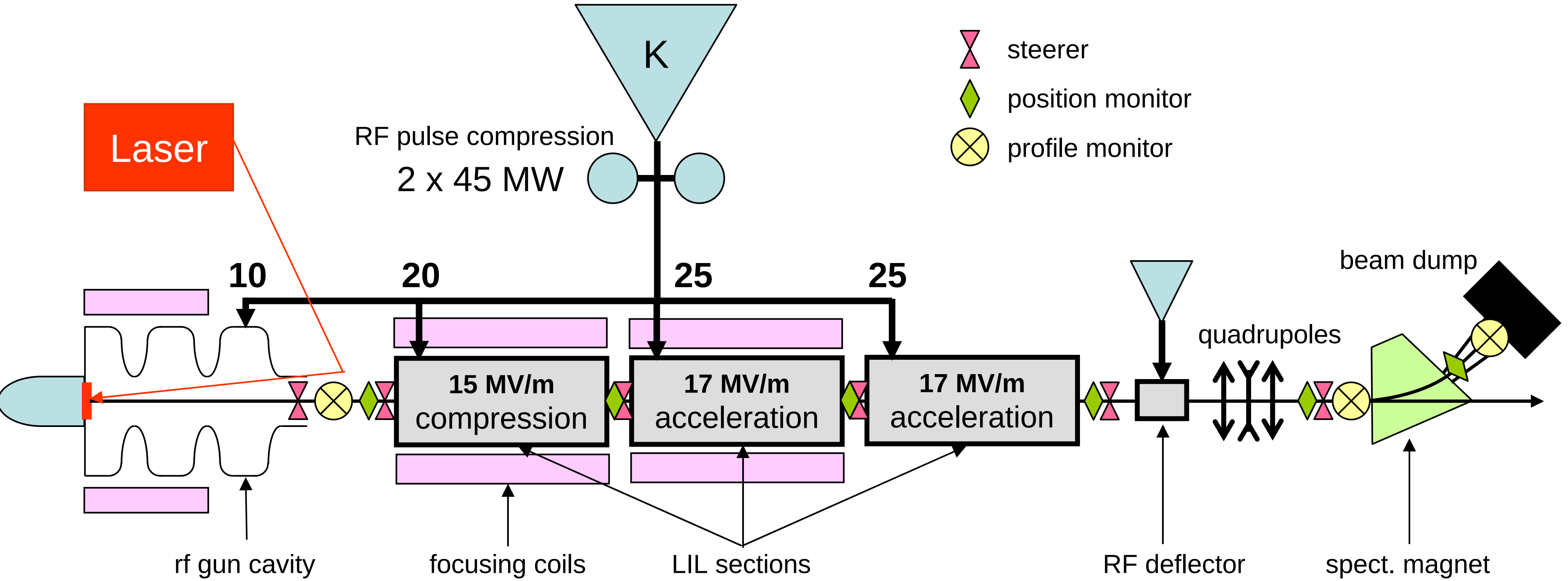
ITB 16.0 m from 2^{nd} dogleg magnet to end of beam dump (optional, not funded yet)

180 MeV Probe Beam Injector

CALIFES =Concept d'Accélérateur LInéairepour Faisceau d'ElectronsSonde

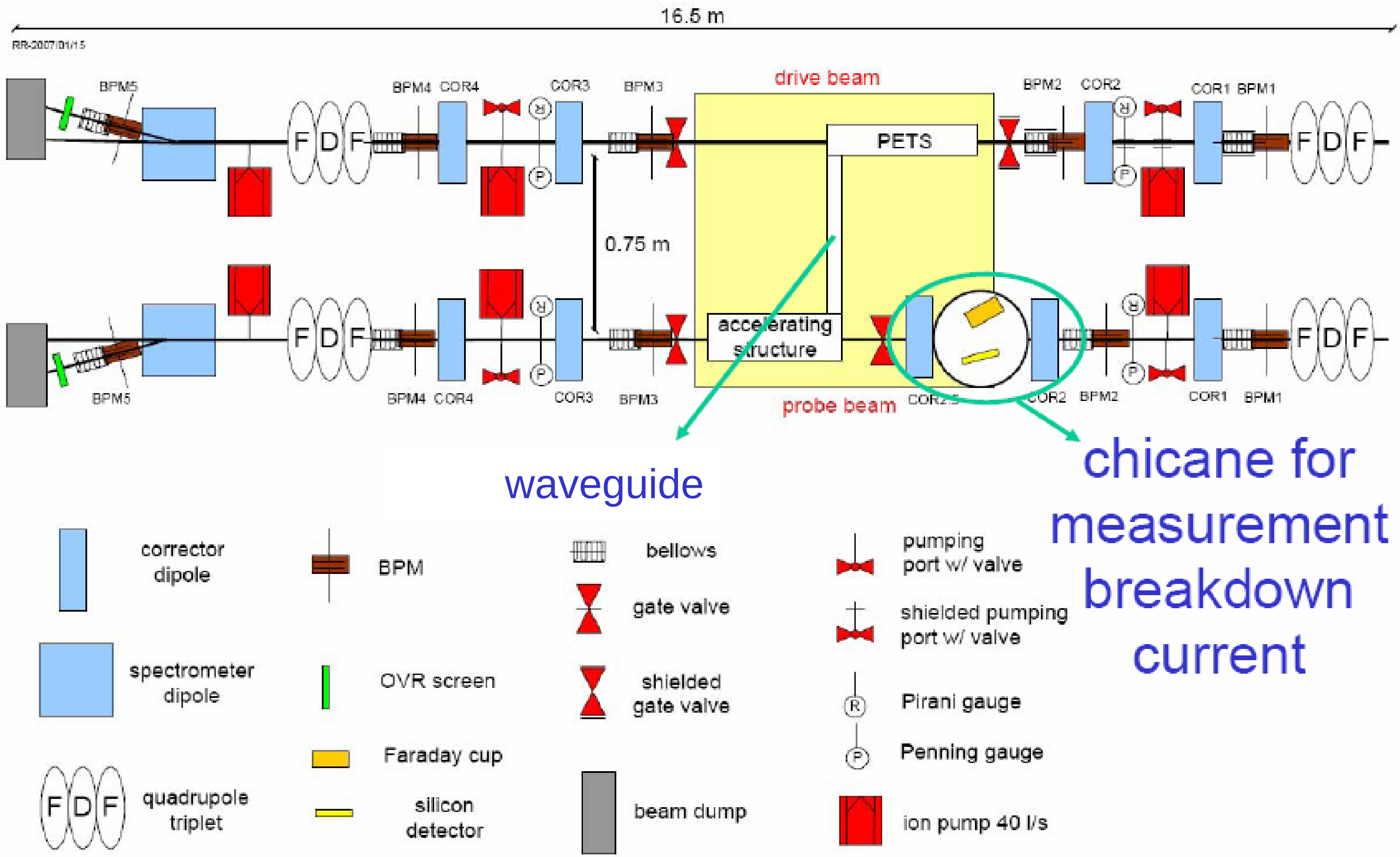
choice of architecture :

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



UPPSALA
UNIVERSITET

Two Beam Test Stand



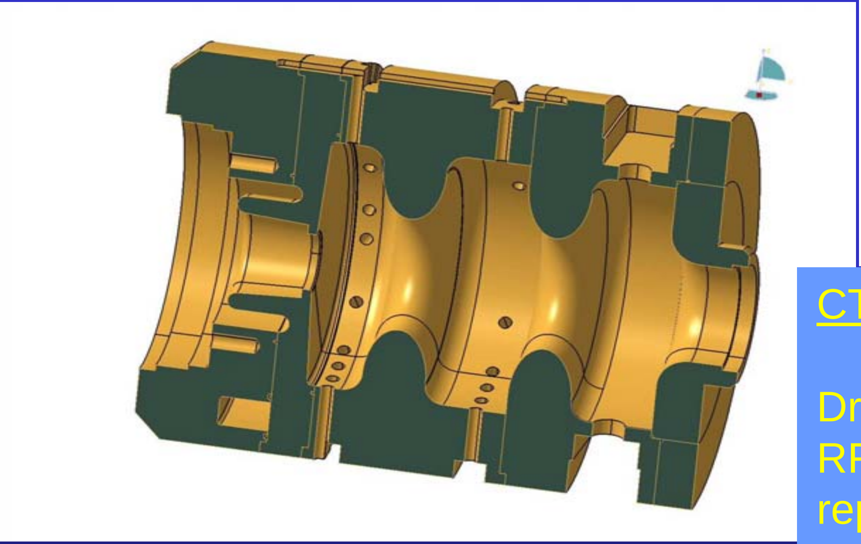
Roger Ruber
17-Jan-2007

SERA

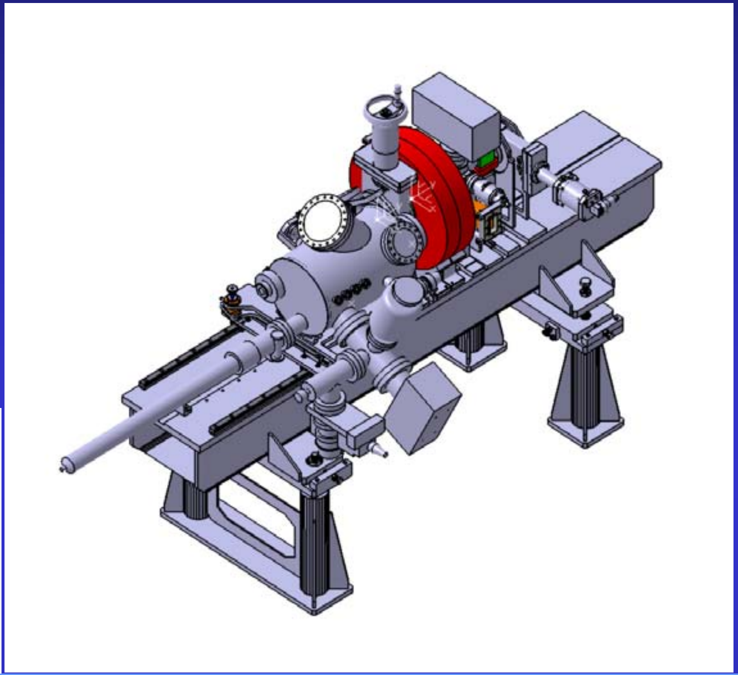
PHIN

CTF3 Drive Beam RF Gun

Test set-up for 2008
If successful this gun will replace thermionic gun of drive beam linac
Phase coding will then be performed with pockel cell switching of laser beam instead of presently use subharmonic cavities



CTF3 Probe Beam RF Gun

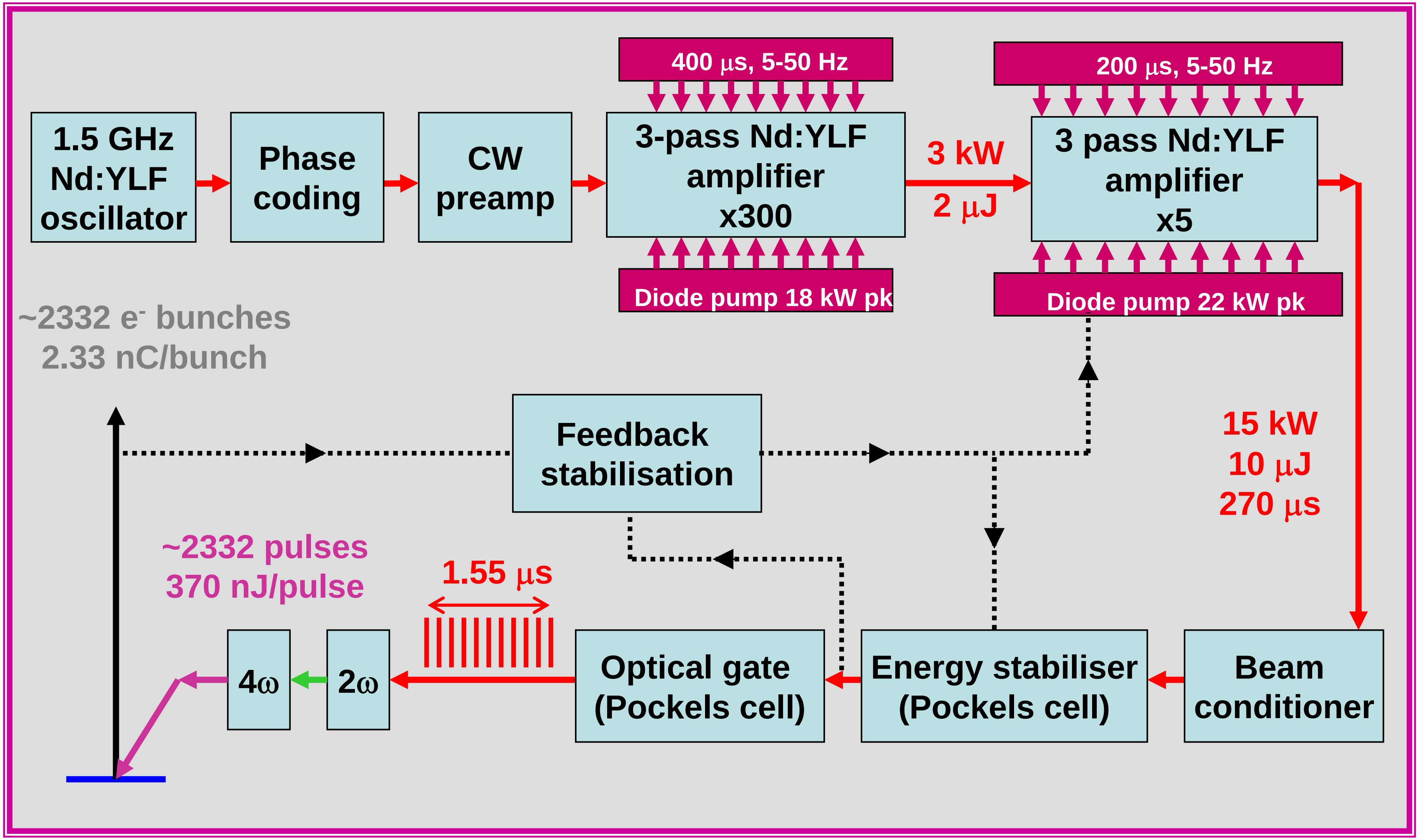


<u>CTF3 Laser system</u>

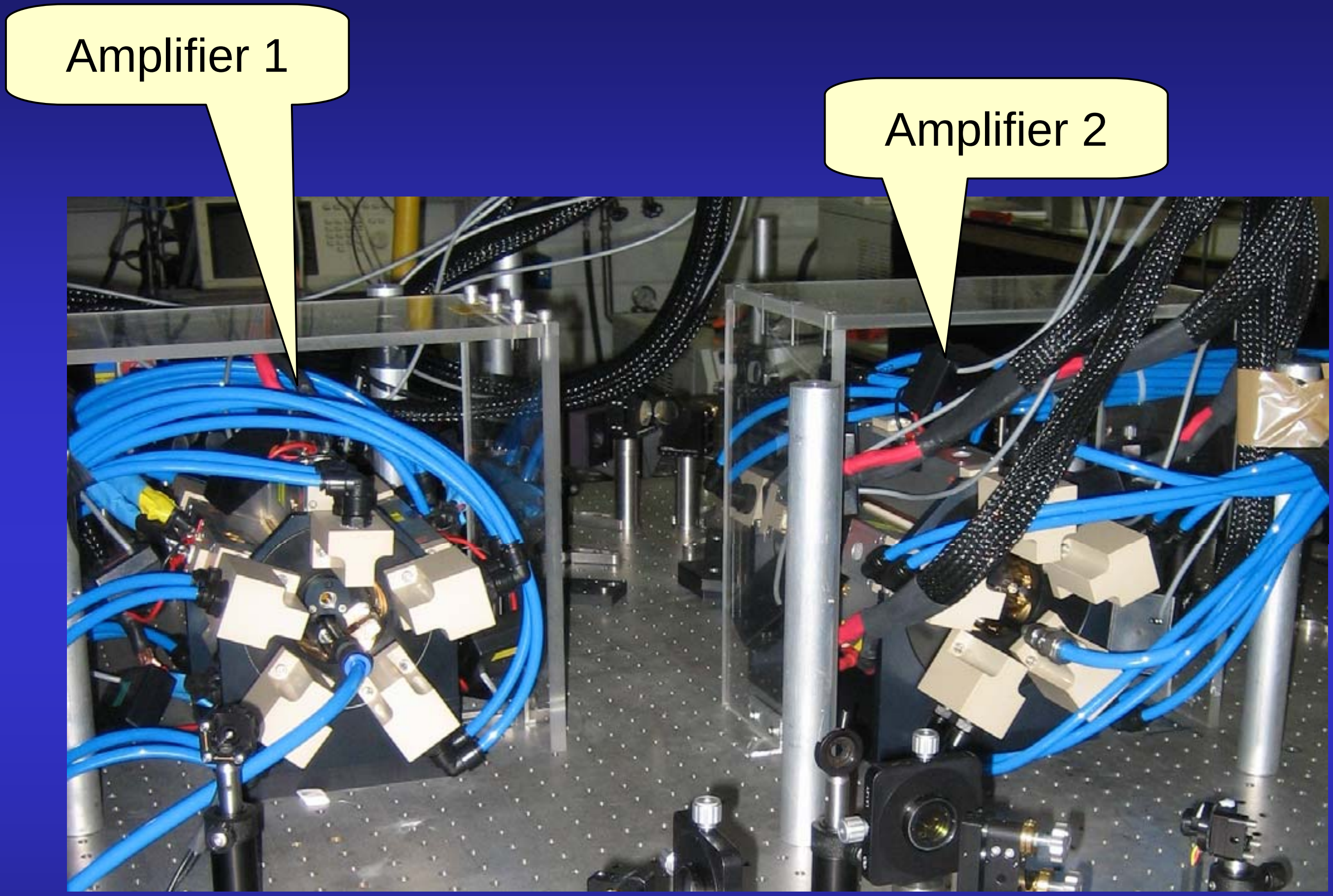
Drive photocathode of future CTF3 drive beam linac RF gun, 2332 bunches of 2.3 in 1540 ns, rep. Rate 1-50 Hz. Stability goal 10^{-4}

Another 140 ns train is picked from the pulse train for RF gun of probe beam RF gun me

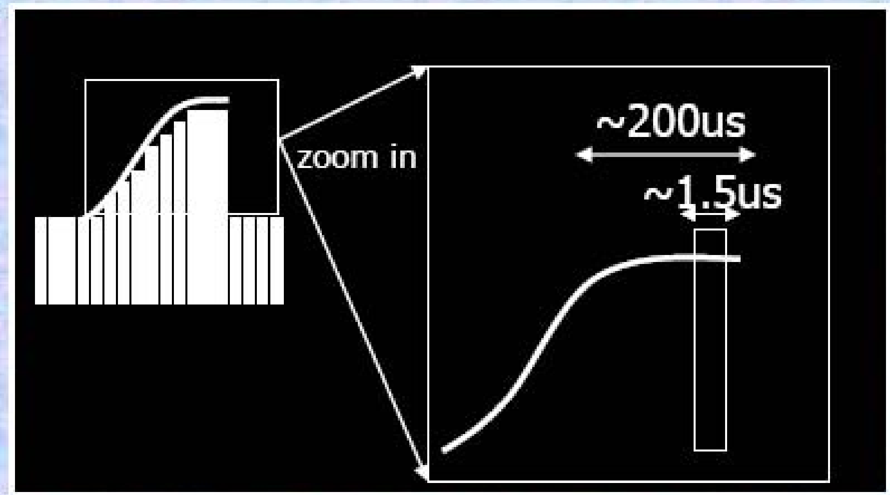
Laser system schematic

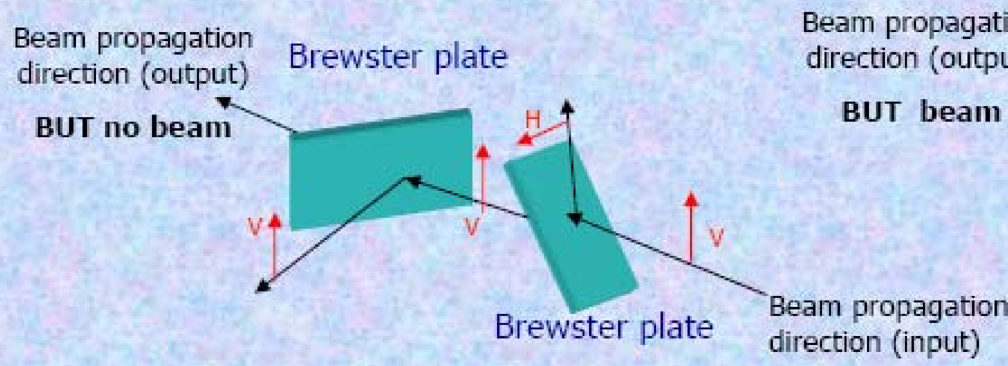


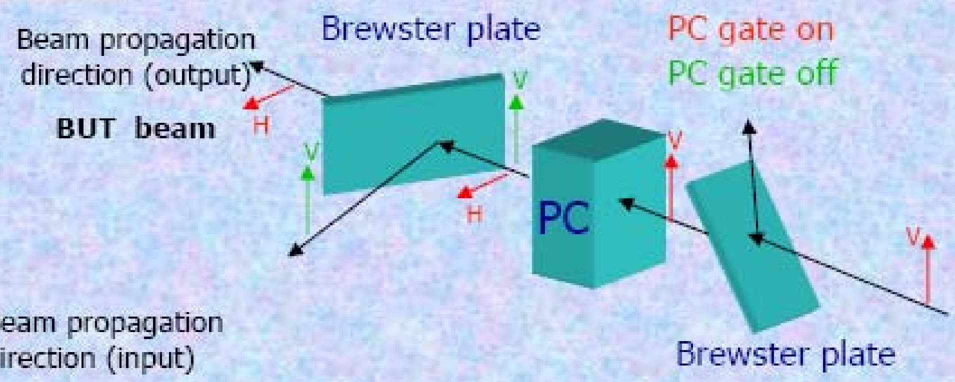
CERN installation


Amplifier 1
Amplifier 2

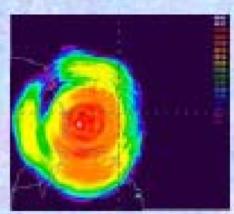
Pockels Cell (PC) Installation







Final beam spot after PC, AMP2 off, AMP1 90A



Power:

Gate: (390 -> 400)us → 0.14W → ~2.8 KW

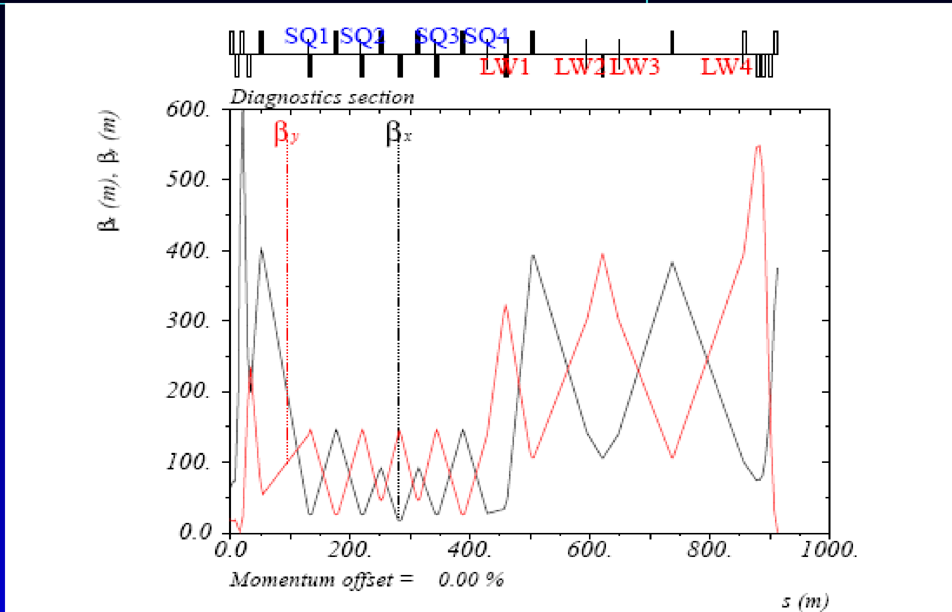
Some open CLIC and CTF3 R&D items

Non interceptive beam profile monitors

Drive beam emittance monitoring:
 typical rms beam size 1 mm, beam current 5-100 A

Main beam emittance monitoring:
 Length of diagnostic section is determined by limit of laser wire technology.
 Strong interest to measure beam size in 100 nm-1μm regime (not only from CLIC)

Diagnostics optics & layout



This is for existing laser wire technology $\sigma_y > 1\mu m$

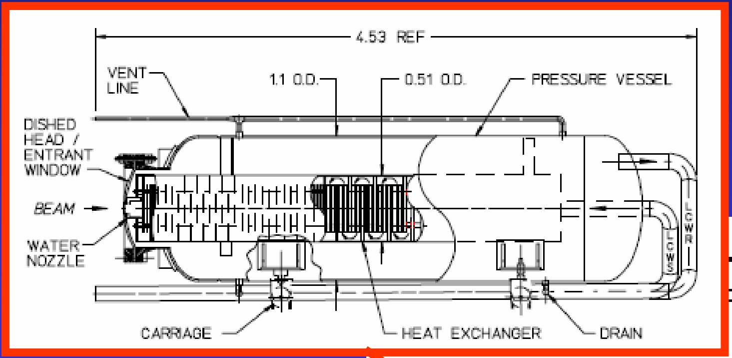
If new BSM measures $> 0.4\mu m$, length $\approx$ 400m.

52 beam dumps for drive beam required

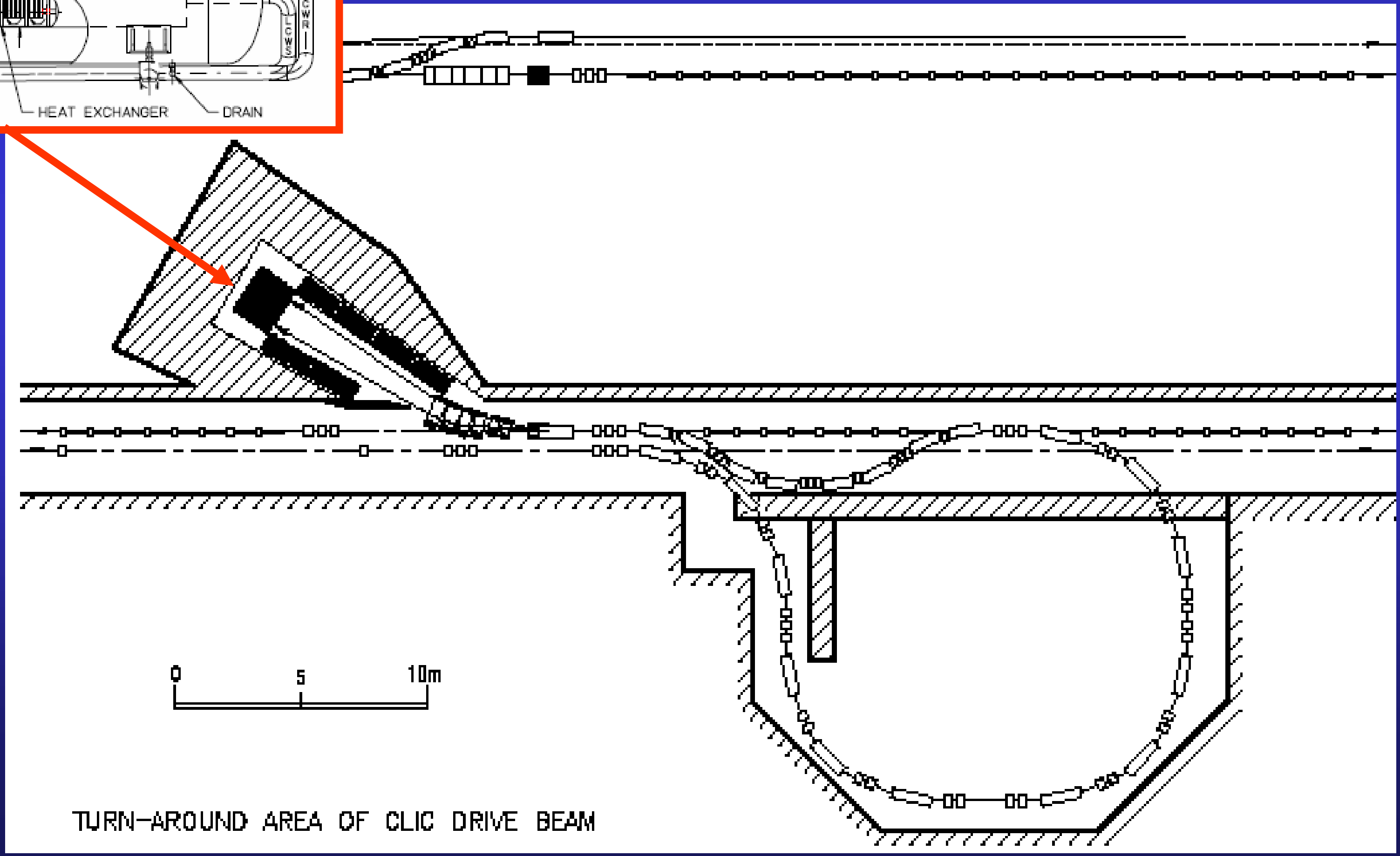
E_{beam}≈300 MeV, $P_{average}$ =300 kW each

6 main beam dumps,

E_{beam}≈1500 GeV, $P_{average}$ =20 MW each



TJNAF
type dump ?



Some examples of CTF3 beam physics and operation issues

Control of longitudinal dynamics is essential to get time structure of drive beam. CTF3 compressor/stretcher chicane, delay loop, combiner ring and TL2 are all equipped with sextupole families to assure isochronous condition up to 2nd order in $\Delta P/P$. But effect of sextupole correction has not been studied with beam due to lack of manpower.

Delay loop together with upstream compressor/stretcher chicane is an ideal test bed to measure energy loss due to CSR. Has not been studied due to lack of manpower.

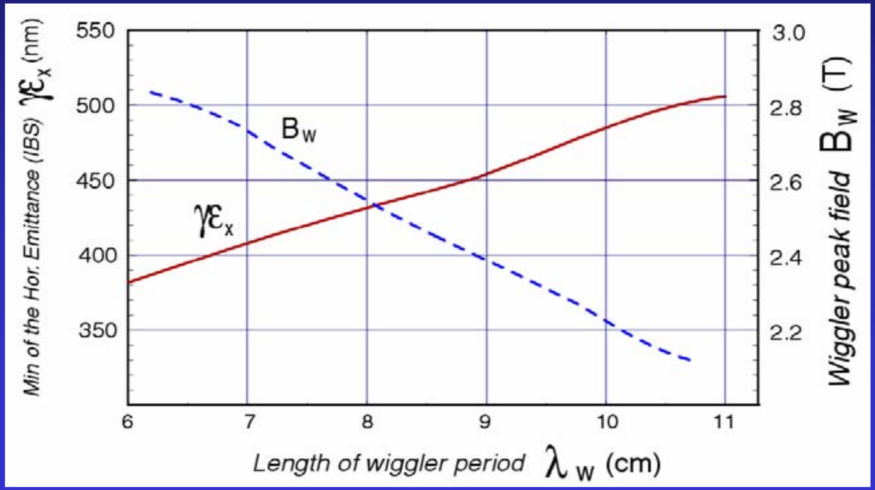
e^+ and e^- source

Requirement: >2 A beam current for 300 ns with 50 Hz repetition rate

Ideally both e^+ and e^- polarized

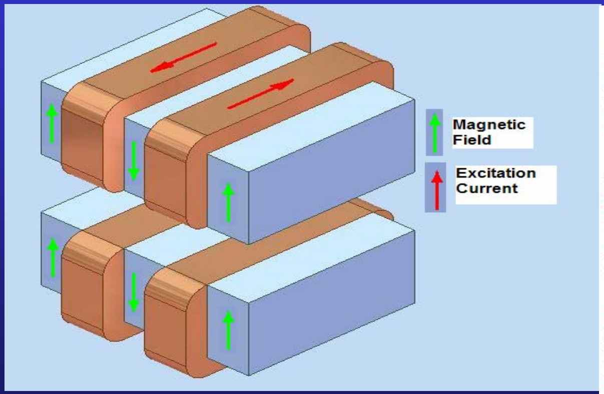
Some studies have been performed for a CLIC Compton source of polarised positrons, but CLIC relies mainly on past NLC R&D

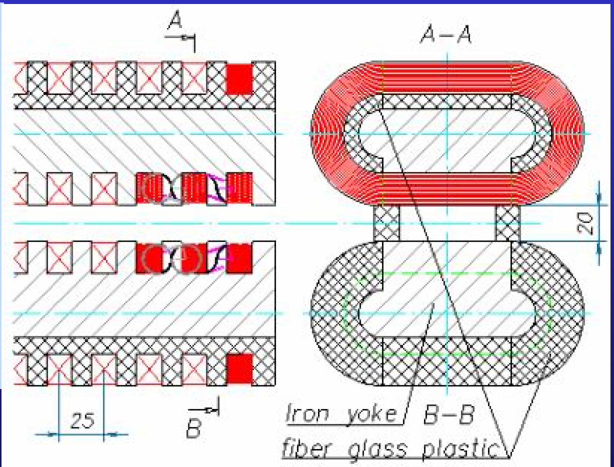
Recently collaboration contract with BINP for development of SC wiggler magnets for CLIC damping ring



Optimum wiggler field strength equilibrium emittance as a function of wiggler period length.

		Permanent magnet	Super conducting (NbTi)
Period length	cm	10	5
Total height of beam aperture	mm	12	12
Peak field on axis	T	1.7	2.5
Length of wiggler module	m	2	2
Transverse field flatness at +/-1cm	%	<0.1	<0.1
Operating temperature	K	Room temperatur e	4.2 K





Conclusions & outlook

- New CLIC parameters to adapt to recent structure tests and results of cost optimizations.
- CTF3 installations and machine experiments on schedule (almost) for feasibility proof by 2010
- Organization of CTF3 as an international collaboration modeled after big particle physics experiment works astonishingly well. Opening CTF3 collaboration to CLIC subjects beyond CTF3 under discussion.

Upcoming CLIC related events

- Workshop on X-band accelerating structures and power sources, CERN June 18-19
- First meeting of CLIC ACE international advisory committee, CERN, June 20-22
- IBS Mini-workshop, Cockcroft Institute/UK, August 28-29
- 1st Workshop on CLIC machine and detector issues, CERN, provisional date October 15-17
- 12th CTF3 collaboration meeting, CERN, ~ mid January 2008