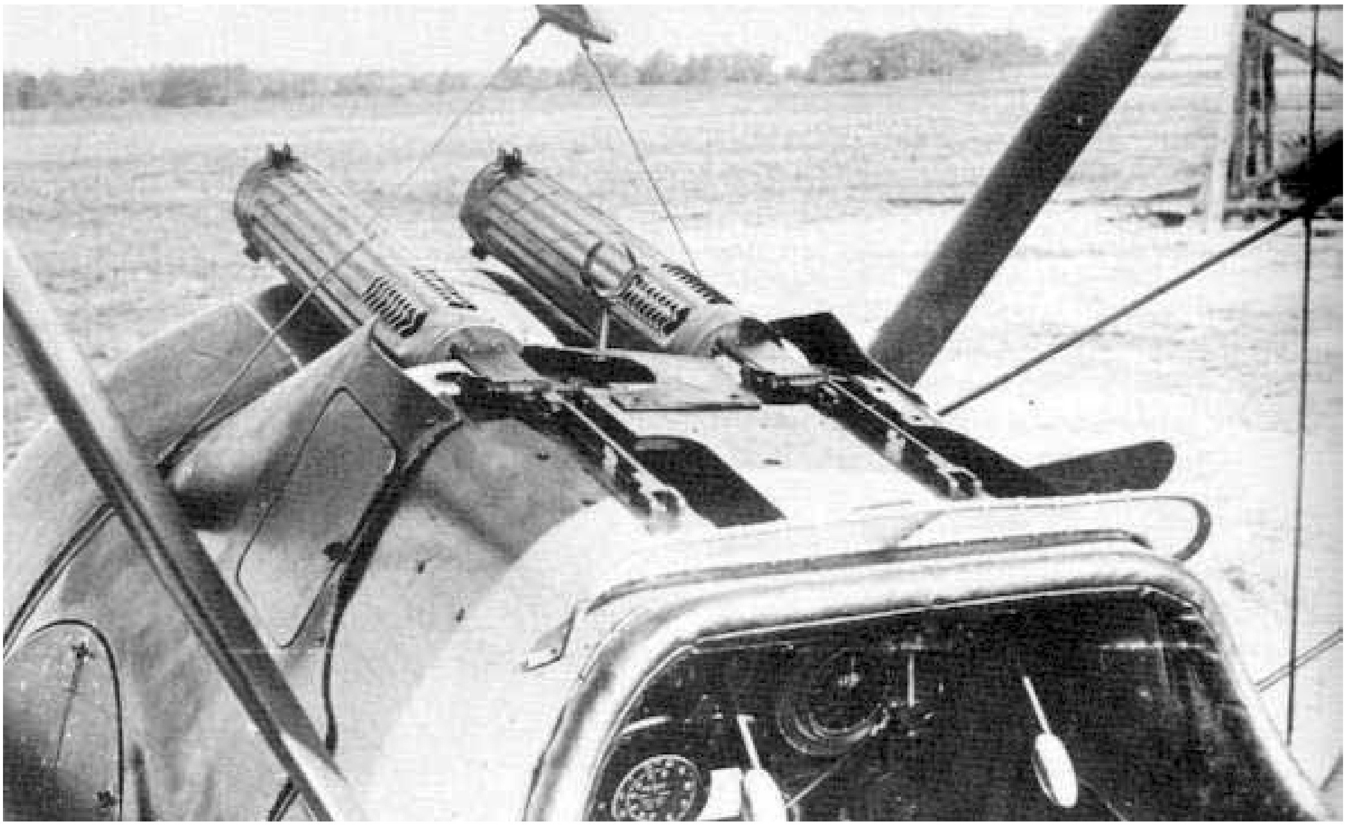
Timing distribution at the LHC

B.G. Taylor CERN/EP

8th Workshop on Electronics for LHC Experiments

Colmar, 9-13 September 2002

Sync or swim



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TTC Common Project collaboration

ALICE integration	O.V. Baillie, H.R. Schmidt
ATLAS integration	P. Farthouat
CMS integration	S. Cittolin, R.N.J. Halsall, W.J. Haynes
LHCb integration	J. Christiansen, R. Jacobsson
BI integration, TTCbi	J.-J. Savioz
TTCvi, TTCvx	P. Gällnö
TTCrx ASIC	A. Marchioro, P.R. Moreira, T.H. Toifl
TTCsr	J. Ferrer-Prieto
Synchronisation	J.C. Da Silva, J.Varela
System modelling	A. Racz
Event builder, LabVIEW	L. Pollet
Irradiation studies	P. Jarron
FERMI clock manager	J.-F. Genat
Subminiature connector	J.-C. Hubert, G. McFarlane
Receiver photonics	M. Ashton, J. Humphries
Spokesman	B.G. Taylor

SL associates	
Controls	G. Beetham
Hadron RF	Ph. Baudrenghien, D. Stellfeld
ST associates	
Elec engineering	L. de Jonge, O. Olsen

A TTC Glossary

TTC	Timing, Trigger and Control
TTCbi	Beam instrumentation interface
TTCcf	Clocks fanout
TTCex	Laser encoder/transmitter
TTClc	Laser controller
TTCmi	LHC machine interface
TTCmx	Laser minitransmitter
TTCmr	Receiver module
TTCoc	Optical tree coupler
TTCos	Orbit synchronizer
TTCpr	PMC receiver
TTCrm	Receiver mezzanine
TTCrx	Receiver ASIC
TTCsr	Simple receiver
TTCtx	Laser transmitter
TTCvi	VMEbus interface
TTCvr	VMEbus receiver
TTCvx	LED transmitter
BGA	Ball grid array (package)
BM	Biphase mark (encoding)
FBT	Fused biconic taper (coupler)
LHCrx	LHC receiver
PCR	Prevessin control room
PLL	Phase locked loop
PRBS	Pseudo random binary sequence
TDM	Time division multiplex
VCXO	Voltage controlled xtal oscillator

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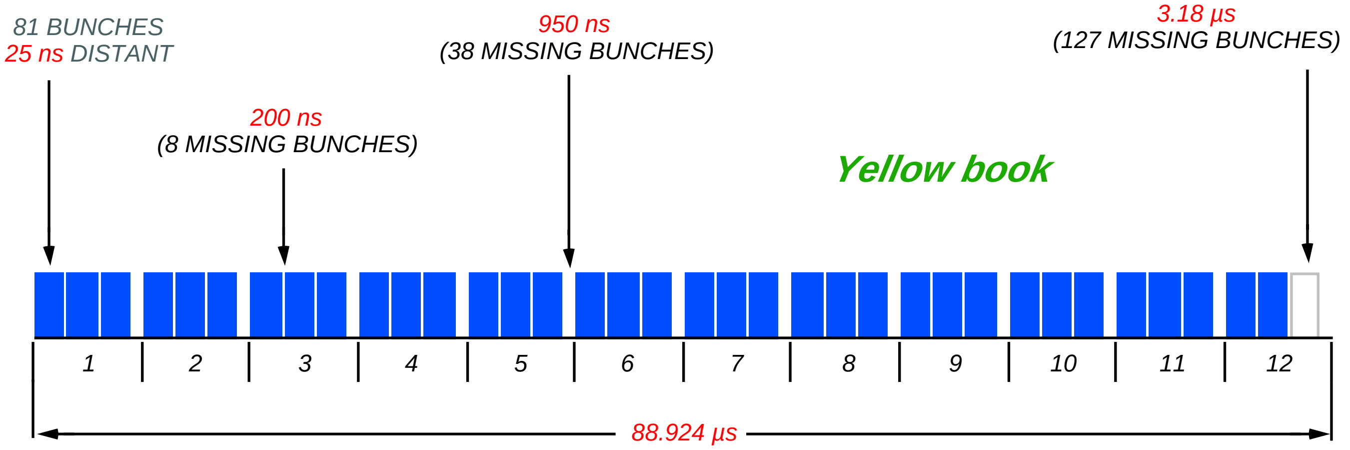
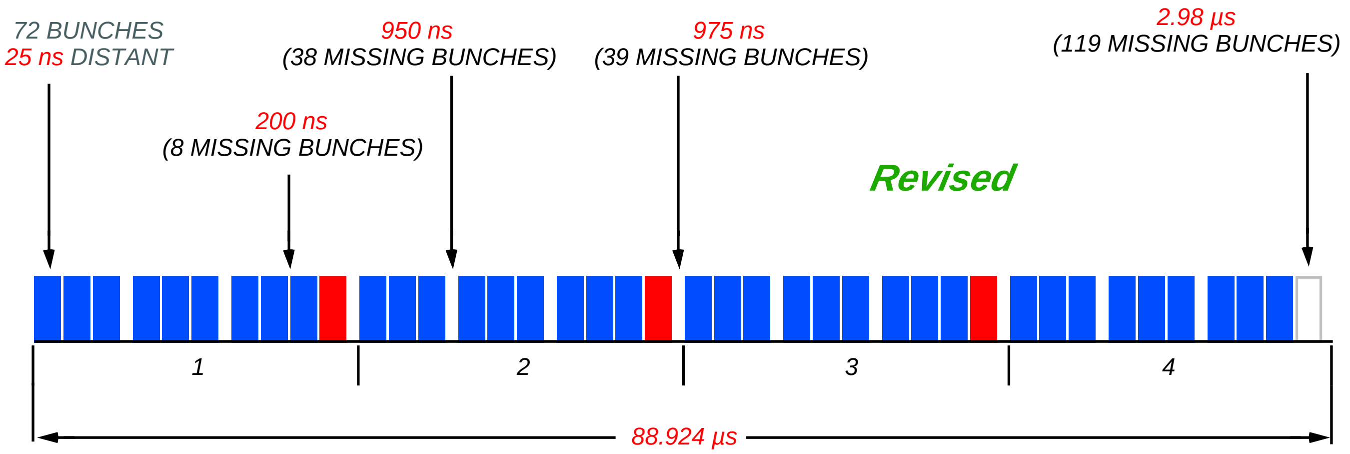
LHC bunch structure (p)





Revolution time	*88.924 µs*
Revolution frequency	*11.246 kHz*
RF frequency	*400.79 MHz (2 x SPS)*
Bunch crossing rate	*40.079 MHz*
No of bunches/beam	*2808*
Filling factor	*0.788*
Bunch train length	*72*
SPS injection kicker gap	*200 ns*
LHC injection kicker gap	*950 ns*
LHC extraction kicker gap	*2.98 µs*
LHC filling time	*4.3 min/ring*
RMS bunch length	*0.075 m, 250 ps*
Interbunch spacing	*7.5 m, 24.95 ns*

Special bunch structures for initial running

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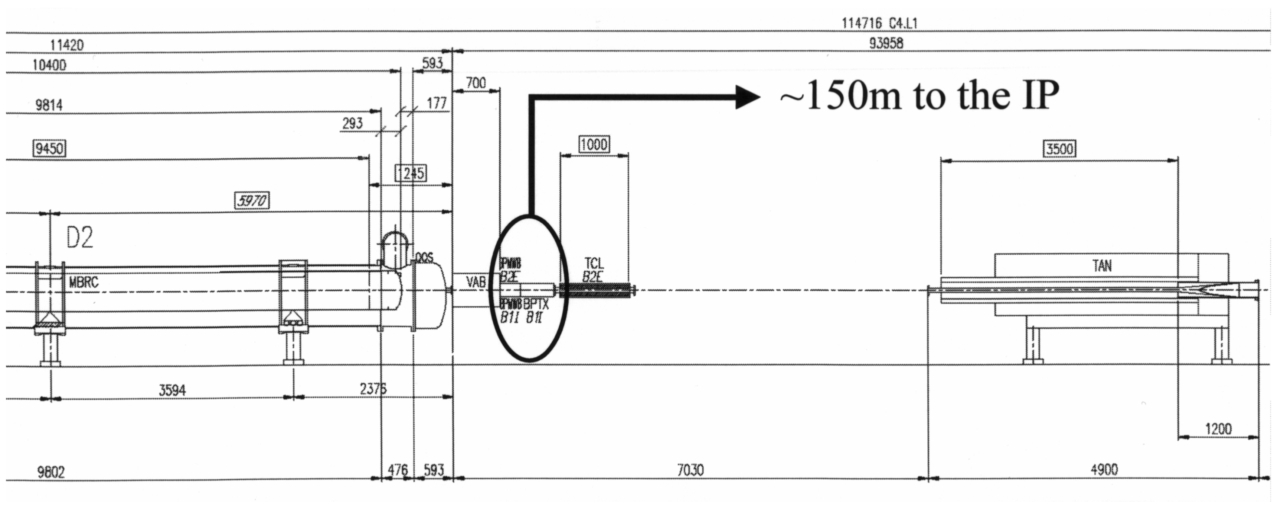
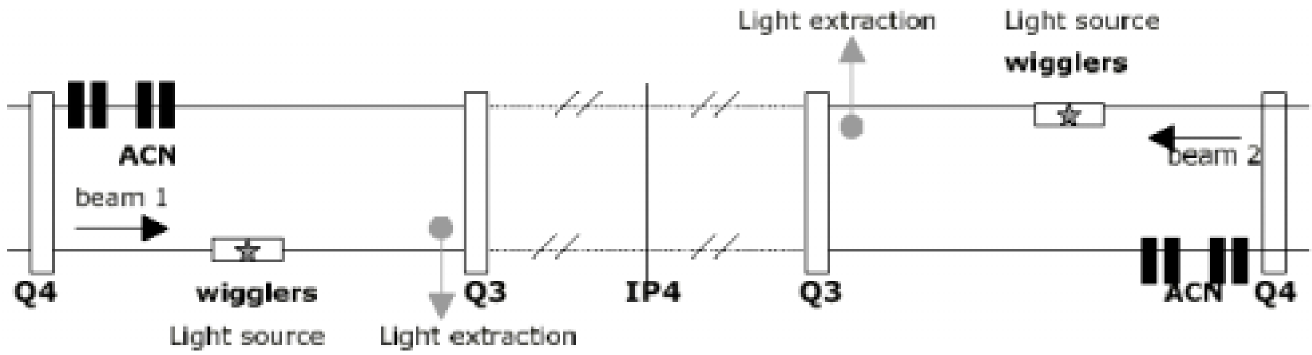
Bunch structure and timing monitors for TTC synchronization



BPTX

Exclusively for use by the experiment

One BPTX on each incoming beam line



Synchrotron light monitor

Precision longitudinal distribution measurement

50 ps resolution over full LHC orbit (89 μs)

10^4 dynamic range (integration over 60 sec)

Clock artefacts

SPS test beams

- *Constant frequency clock to experiments*
- *SPS rephased to this clock before each spill*
- *No clock holes if RF divider reset disabled*

SPS as injector

- *Sync SPS to required LHC injection phase*
- *1 ms hole in SPS RF/5 and SPS Orbit signals*
- *Occurs before each CPS -> SPS transfer*

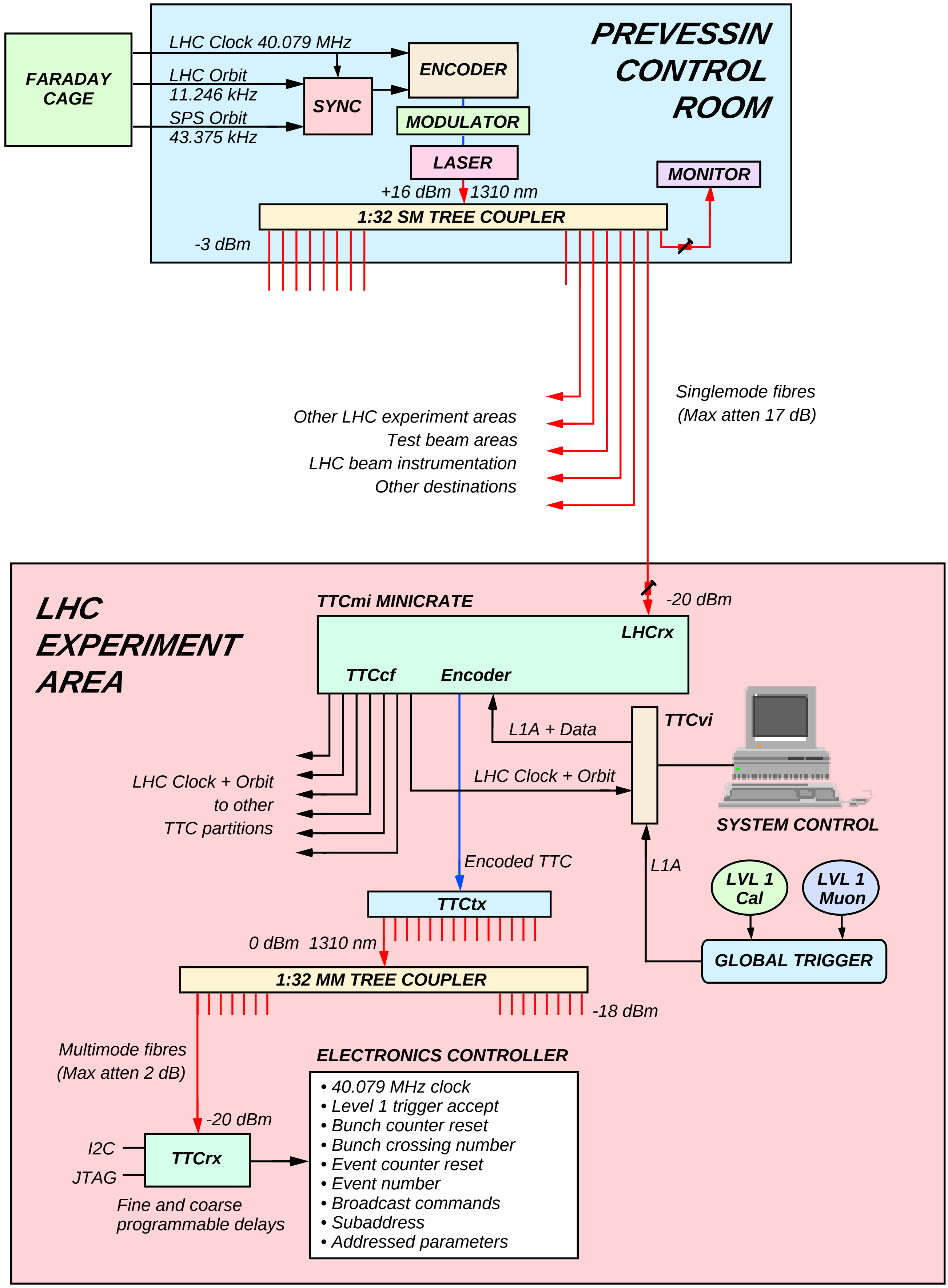
LHC

- *Timing reset prior to each fill/ramp/collide run*
- *1 ms hole in 40.08 MHz and LHC Orbit signals*
- *Occurs only before 1st SPS -> LHC transfer*

SPS and LHC TTC systems will fill 40.08 MHz holes

- but possible phase perturbation on resync

Overall TTC Distribution (from BA3)



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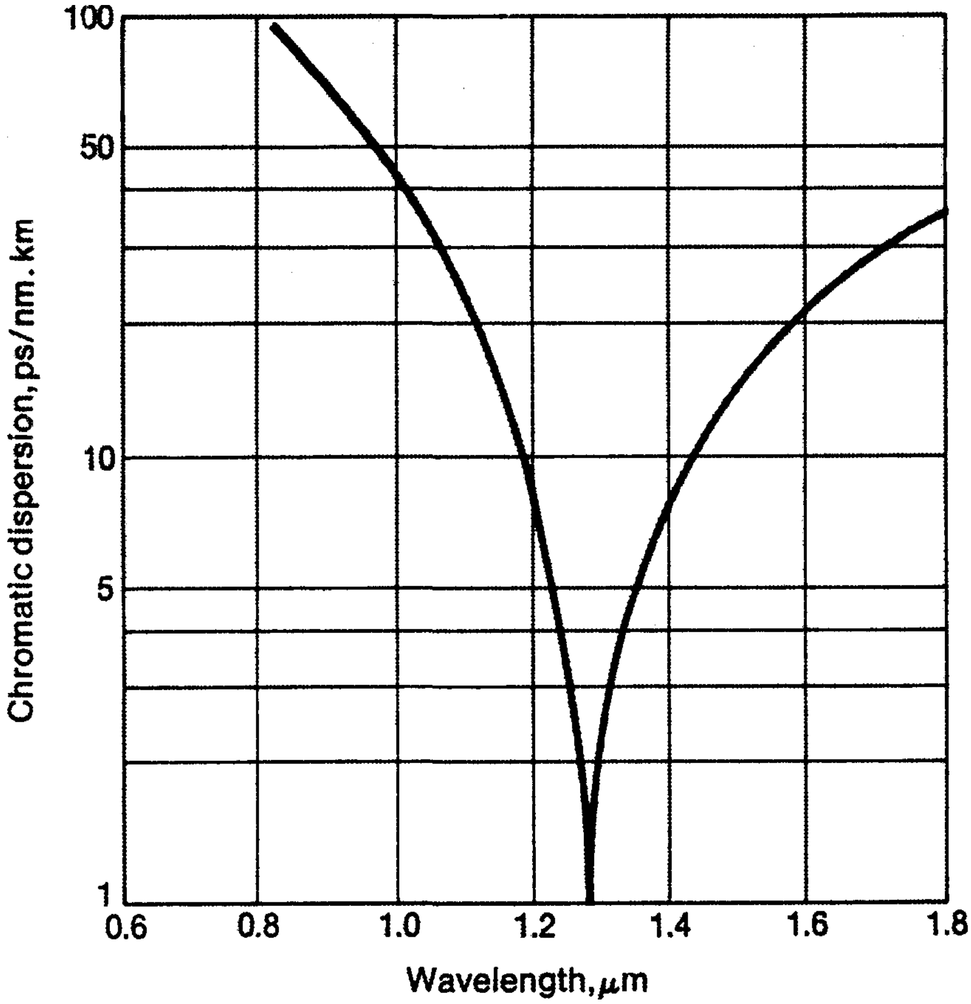
Chromatic dispersion of fibre



Chromatic dispersion over 100m

(= material dispersion, neglecting waveguide dispersion)

	830 nm	1310 nm
LED transmitter (80 nm wide)	640 ps	< 24 ps
Laser transmitter (8 nm wide)	64 ps	< 3 ps

1310 nm tolerates LEDs for small test setups

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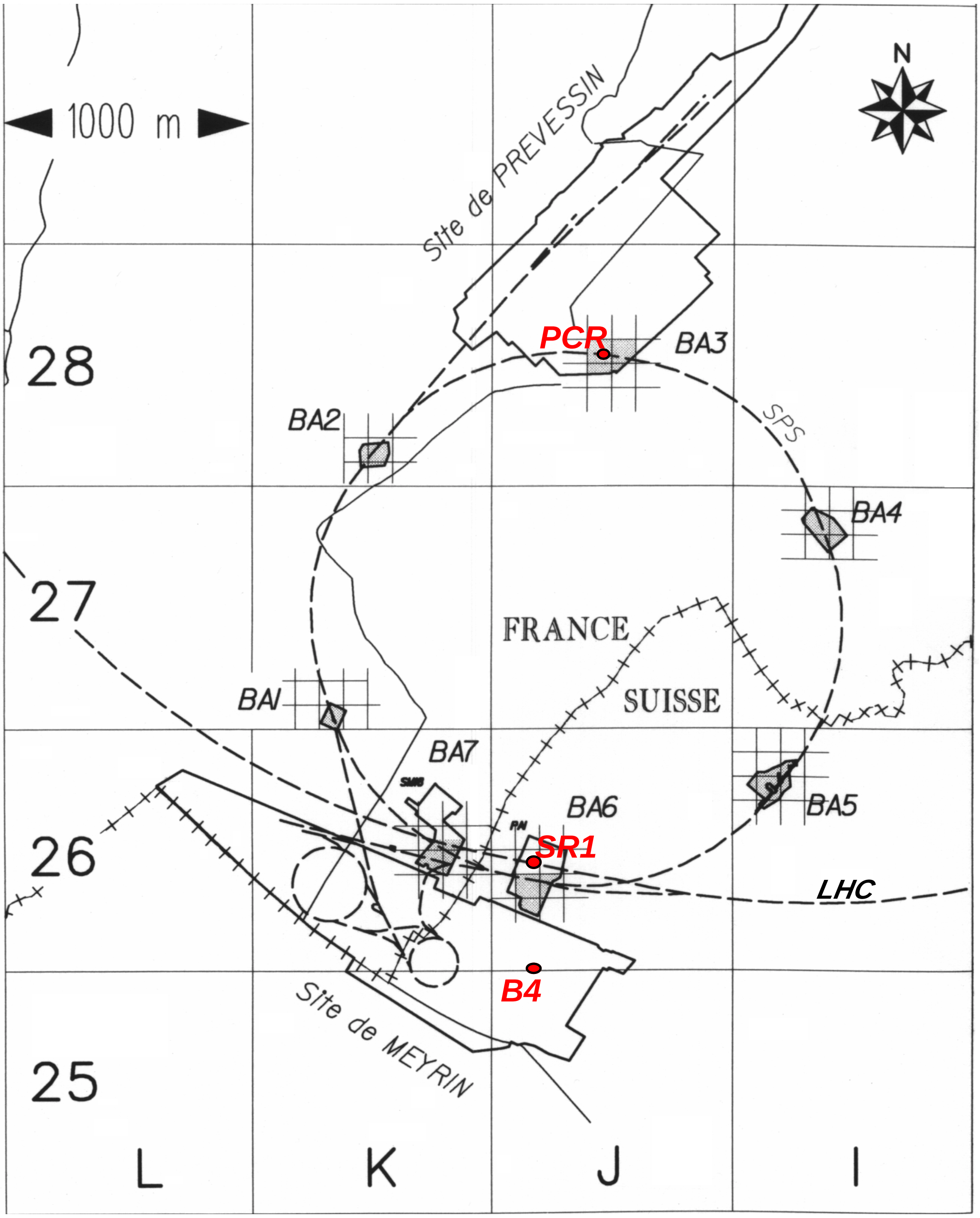
PCR – B4



PCR – SR1

Direct 2.1 km Via SPS 5.6 km

Final 3.8 km (48 MM + 144 SM fibres)

PCR – B4

Via SPS 6.5 km Alternative routing 4.8 km

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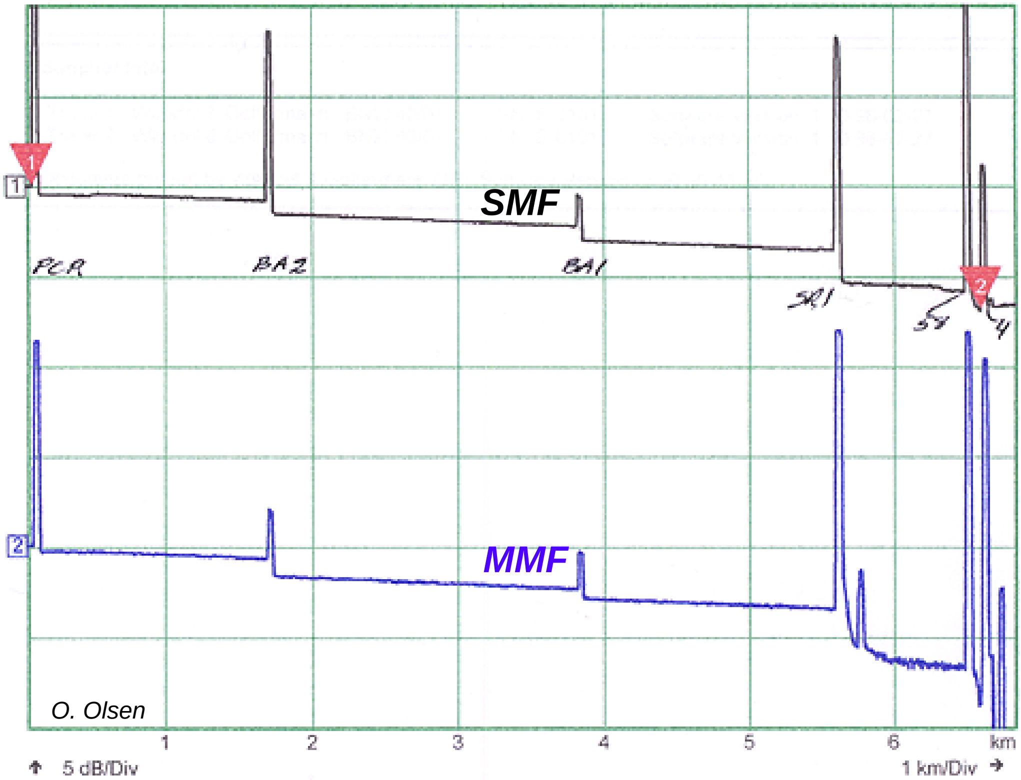
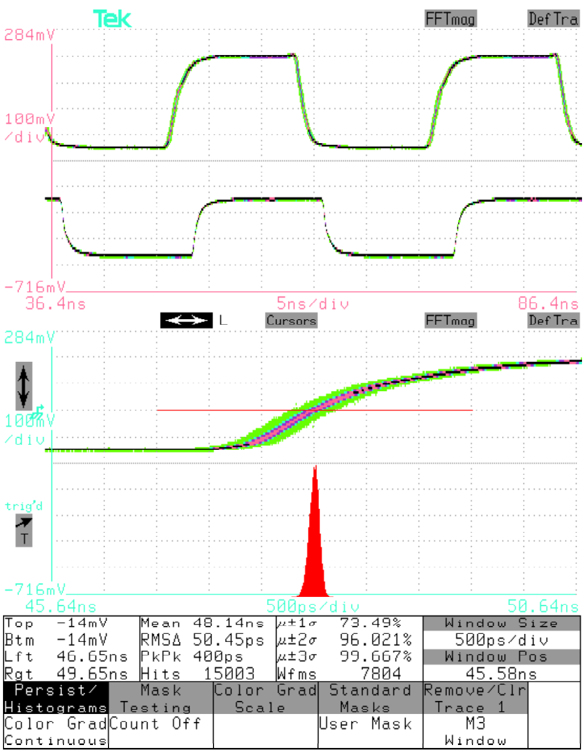
Optical distribution fibres

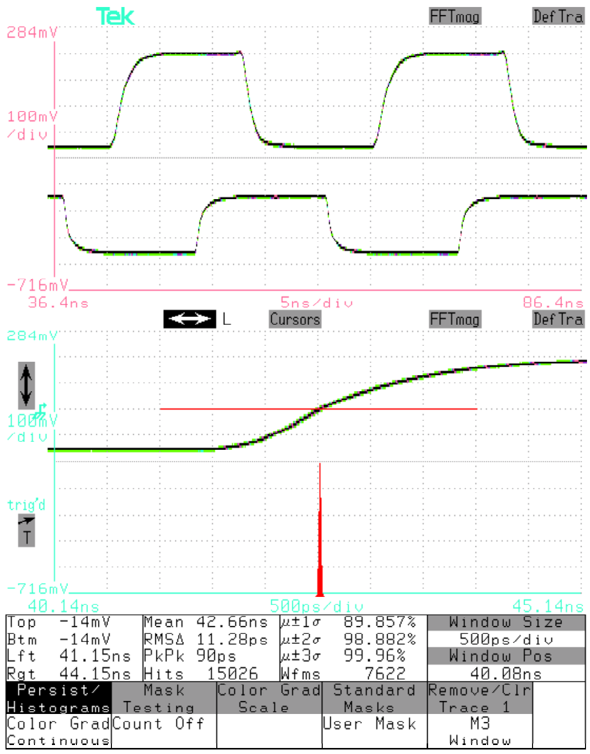
PCR – SR1 – B4



B4 – PCR – B4 (13 km)

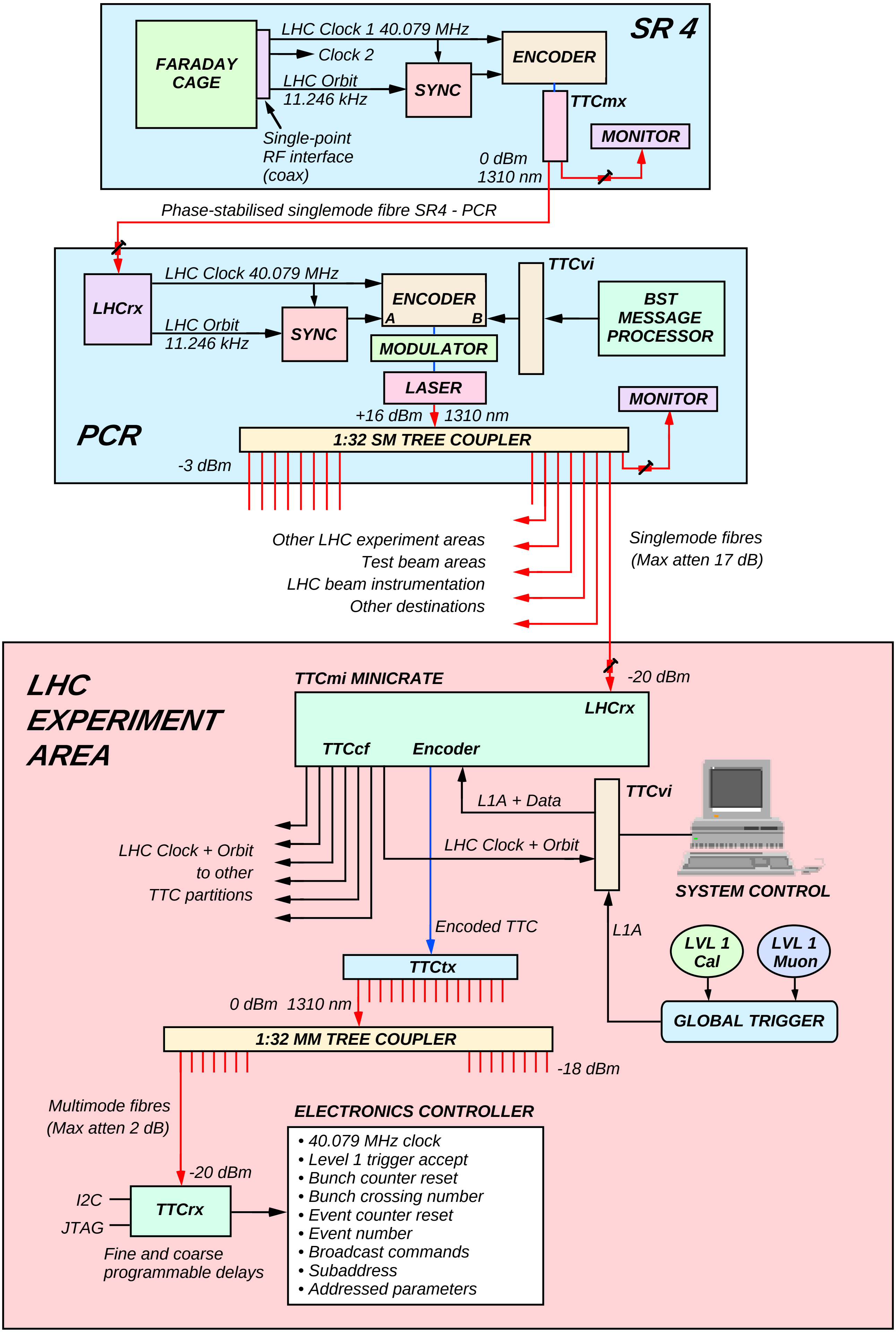


MMF (restricted mode launch)



SMF

Overall TTC Distribution (from SR4)



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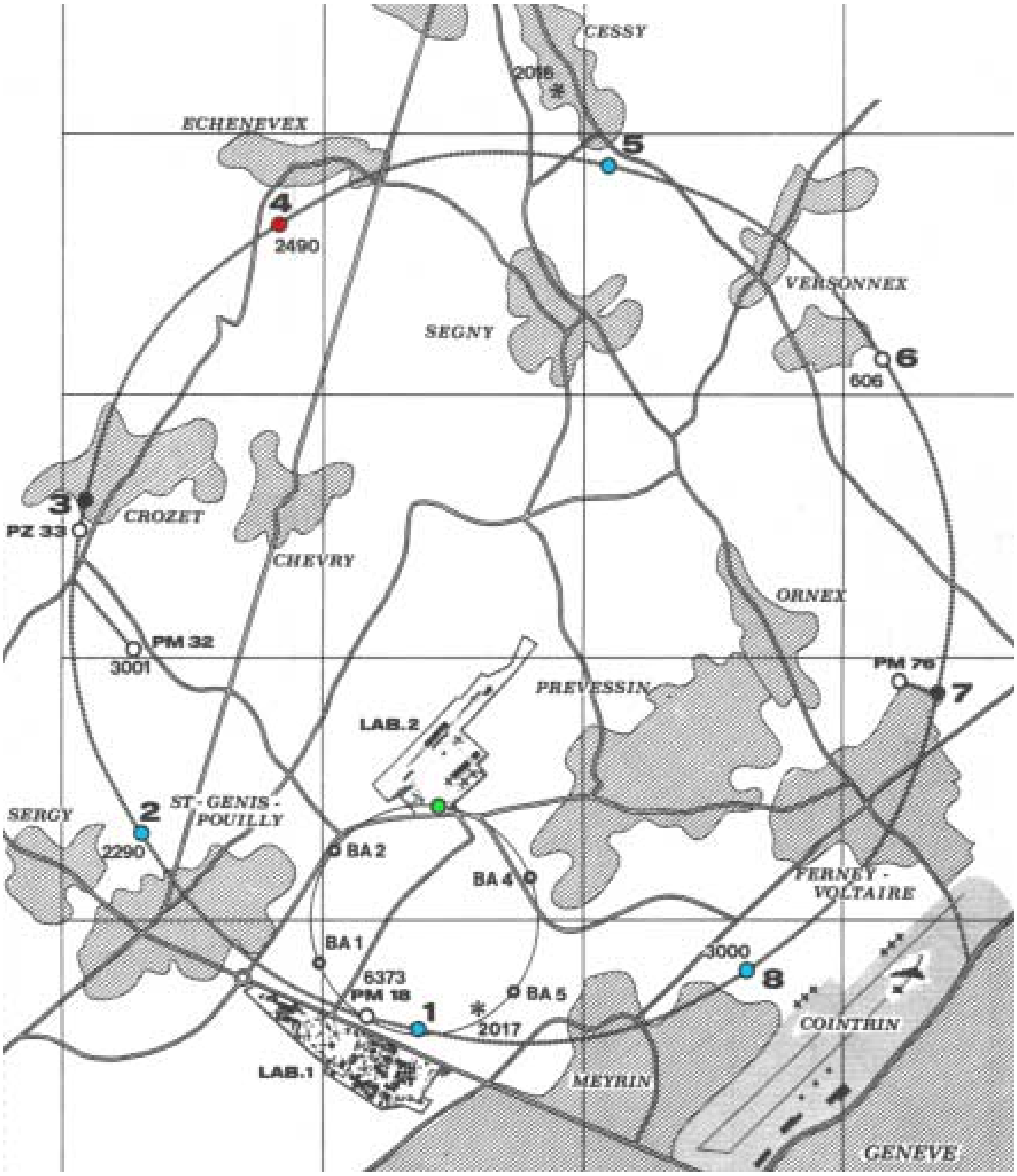
Optical fibre lengths



SR4 (RF) – PCR		9.5 km
PCR – SR1 (ATLAS)		3.8 km
PCR – SR2 (ALICE)		5.4 km
PCR – SR5 (CMS)		10.1 km
PCR – SR8 (LHCb)		4.6 km

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Phase stability of fibres

B4 - SR1 - PCR - SR4 - PCR - SR1 - B4 (28.6 km) SMF

PCR – PS

4.6 km normal singlemode fibre

50 ps diurnal + 50 ps seasonal

<1998 with 269m on surface: 150 ps

SR4 – B4

9.5 km phase stabilised + 4.8 km normal SMF

Installation depth ~ 1m

Diurnal variation - 1-2 fine deskew steps

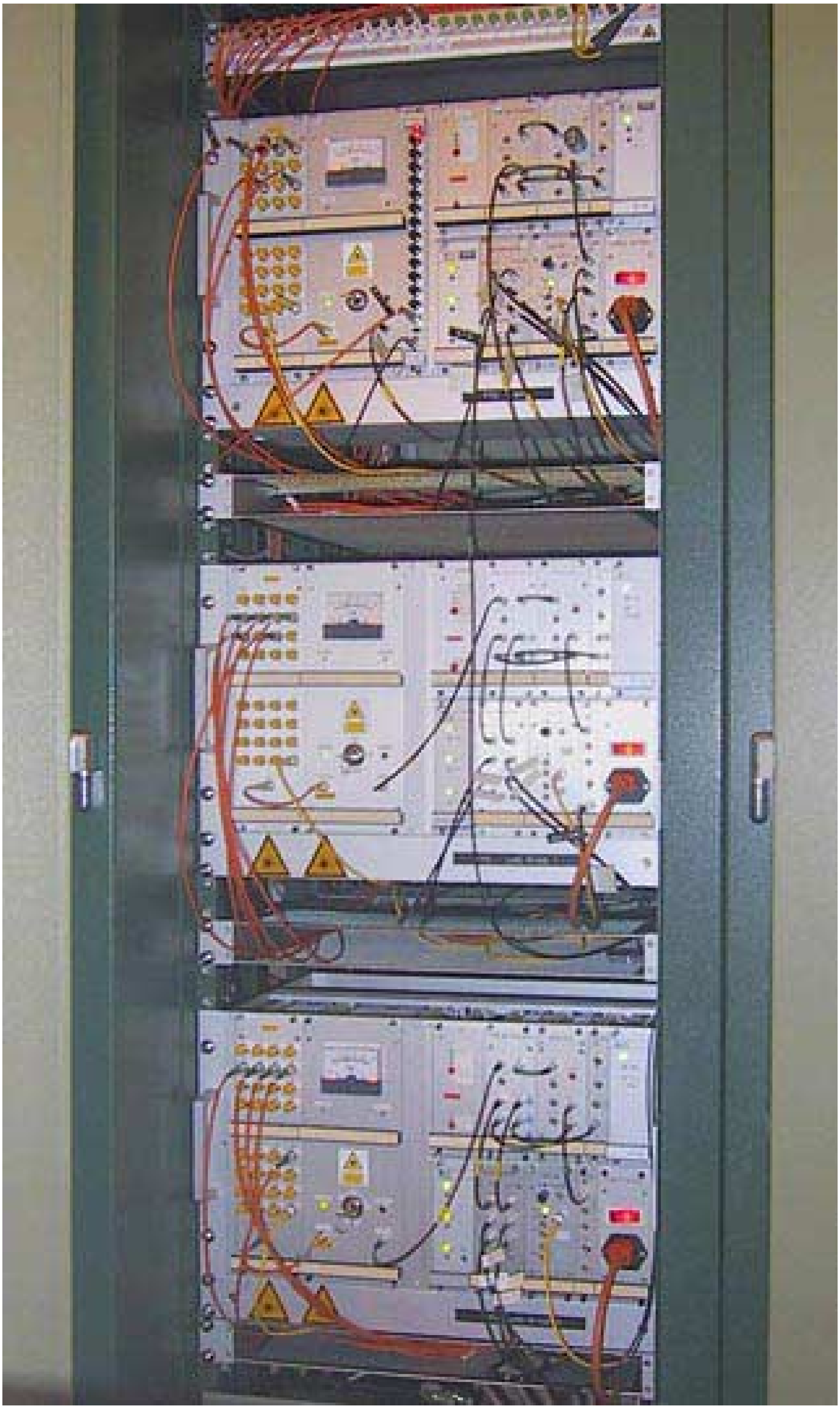
Seasonal variation - slow compensation

PCR transmitter rack

SPS
transfer
lines

LHC
ring 1

LHC
ring 2



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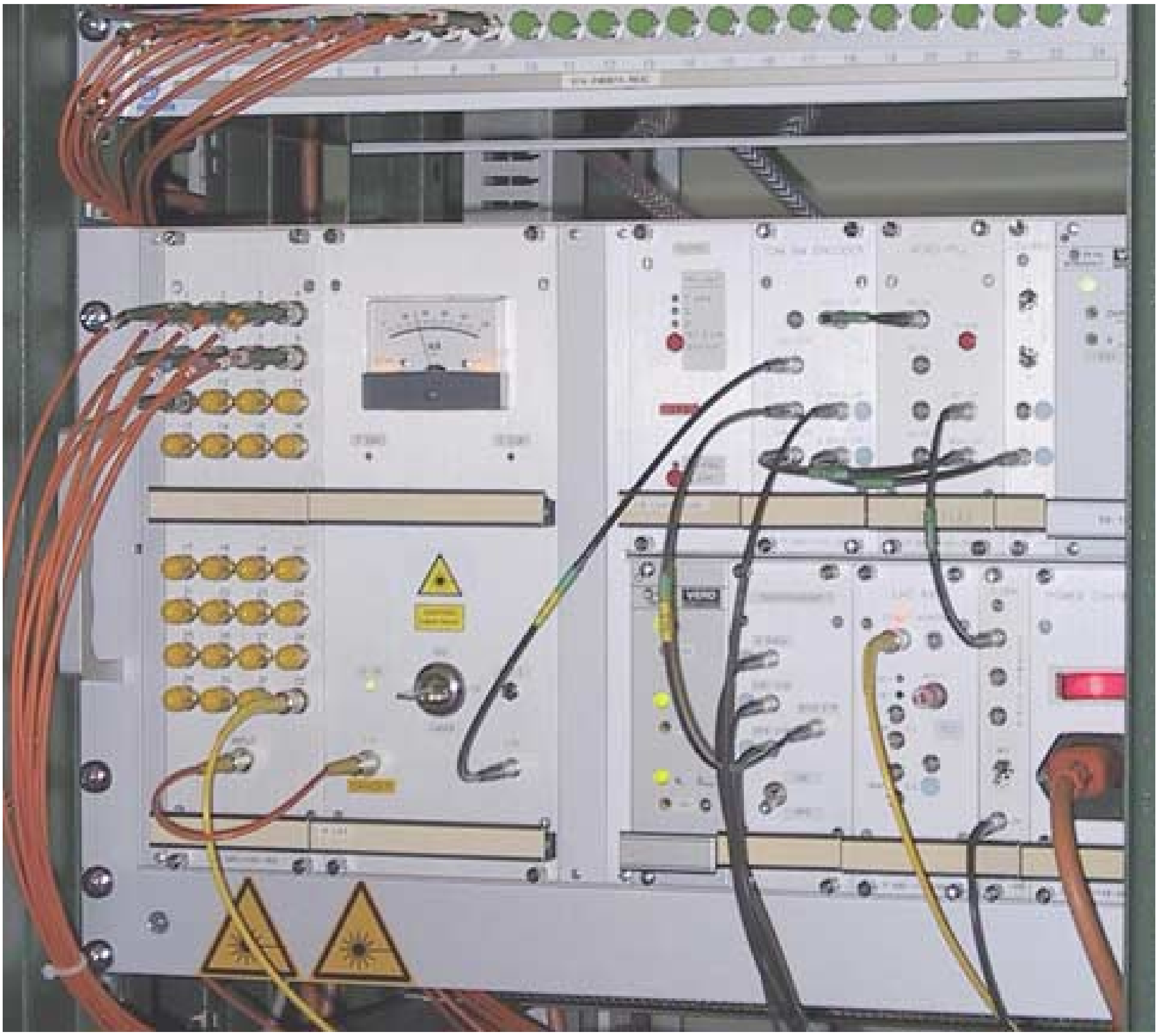
PCR transmitter



OL364A-40 1310 nm laser diode (+16 dBm)

± 0.1 °C temp control

32 (+) singlemode outputs at -3 dBm

Receiver/decoder for link from SR4

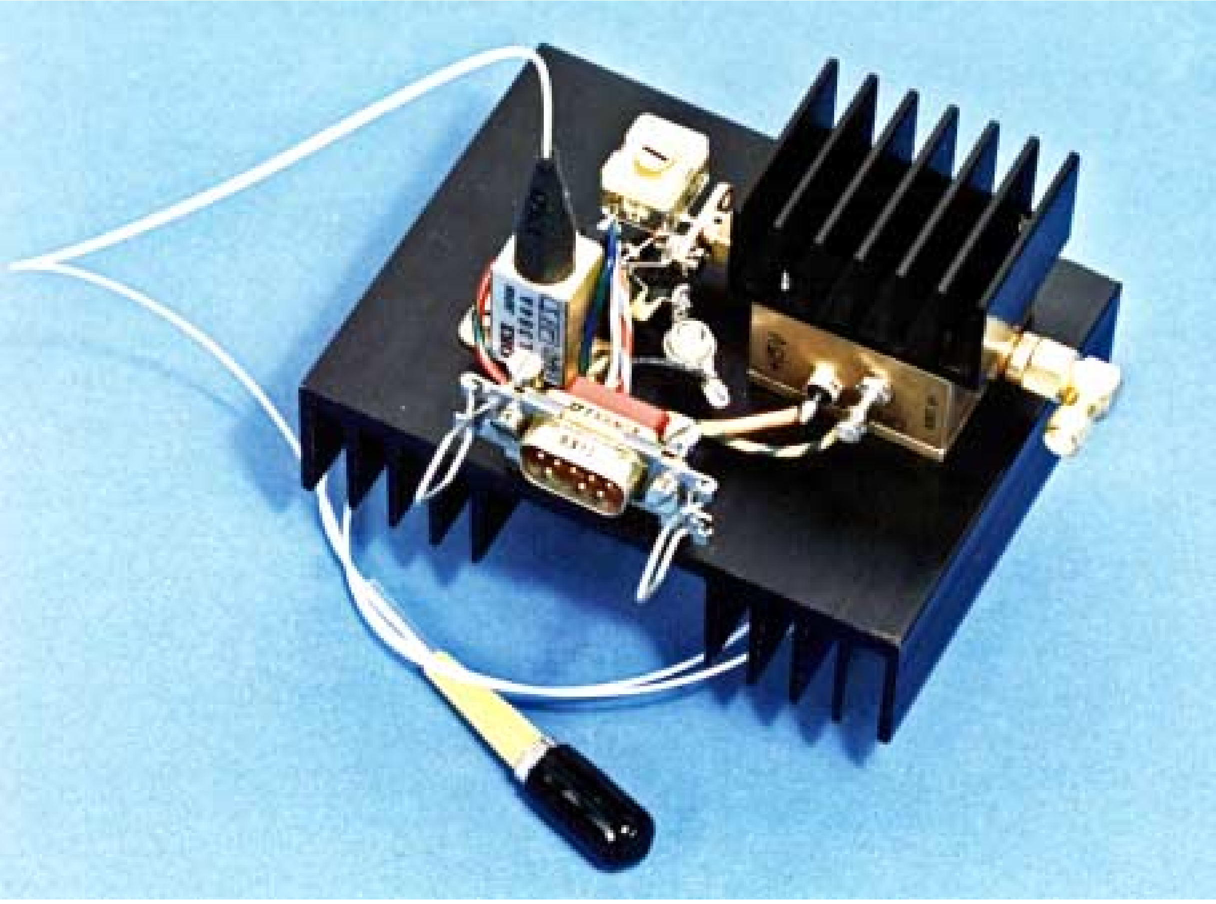
PLL cleanup of clock

Synchronizer for LHC/SPS orbit inputs

Local monitor

LHC ring 1 + LHC ring 2 + SPS + Spare

Laser head module



Singlemode or multimode

$\Delta\lambda$ typically 5 nm

2.4v 1.2A Peltier cooler

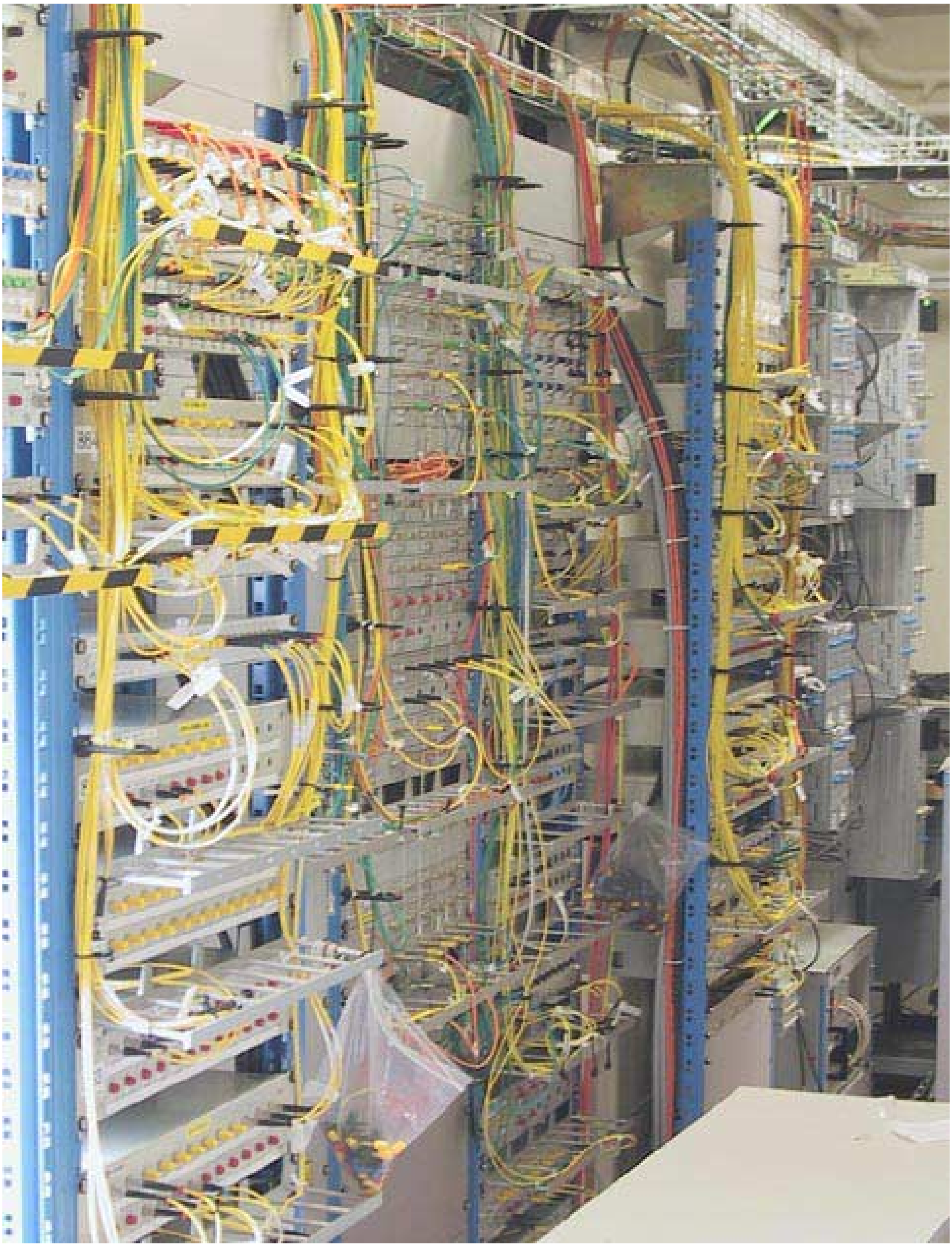
Integrated thermistor

Ferrite bead bias T, I_b 160 mA

1 GHz 400 mW RF modulator

No failures since 1993

PCR optical patchpanel



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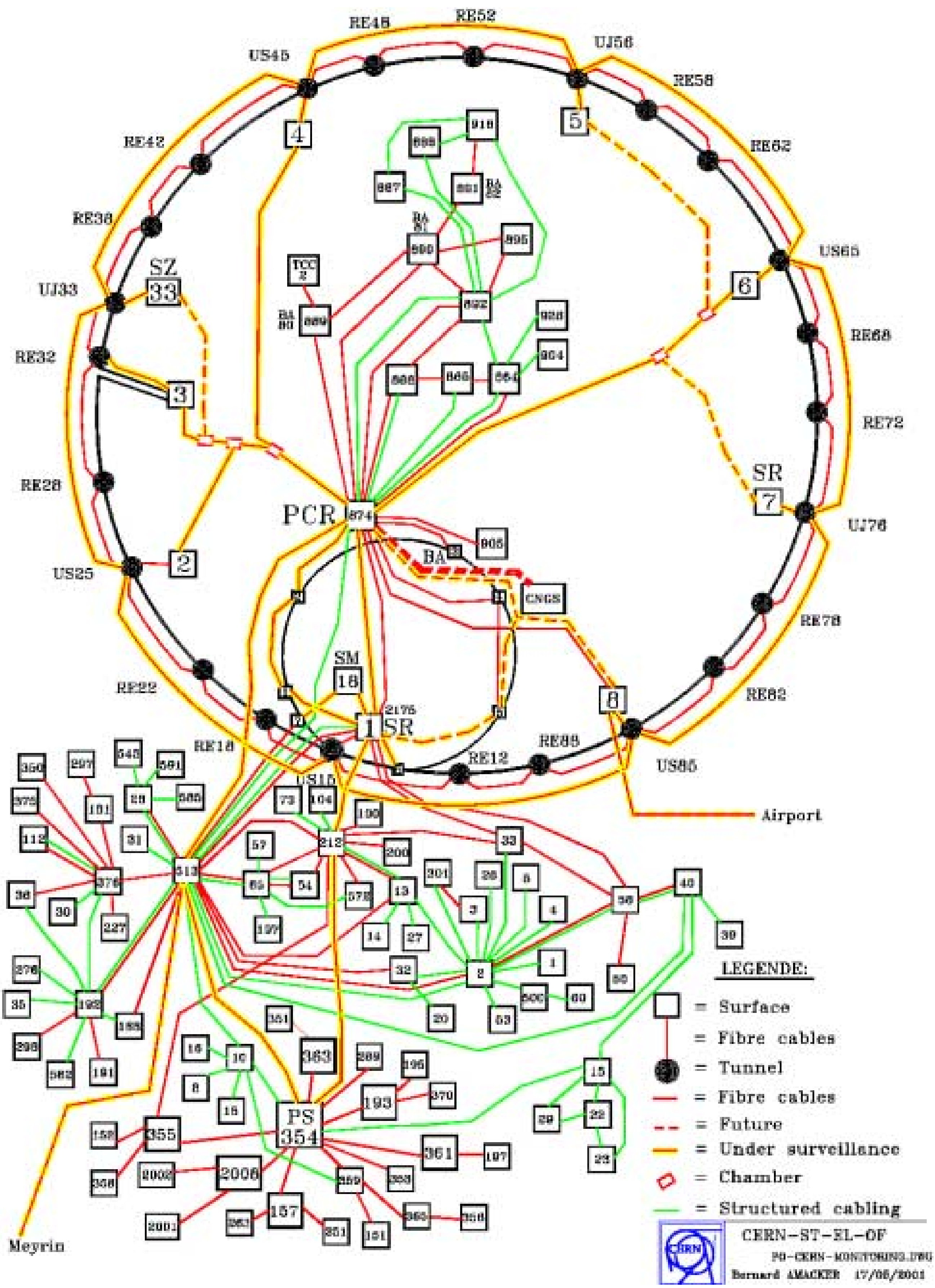
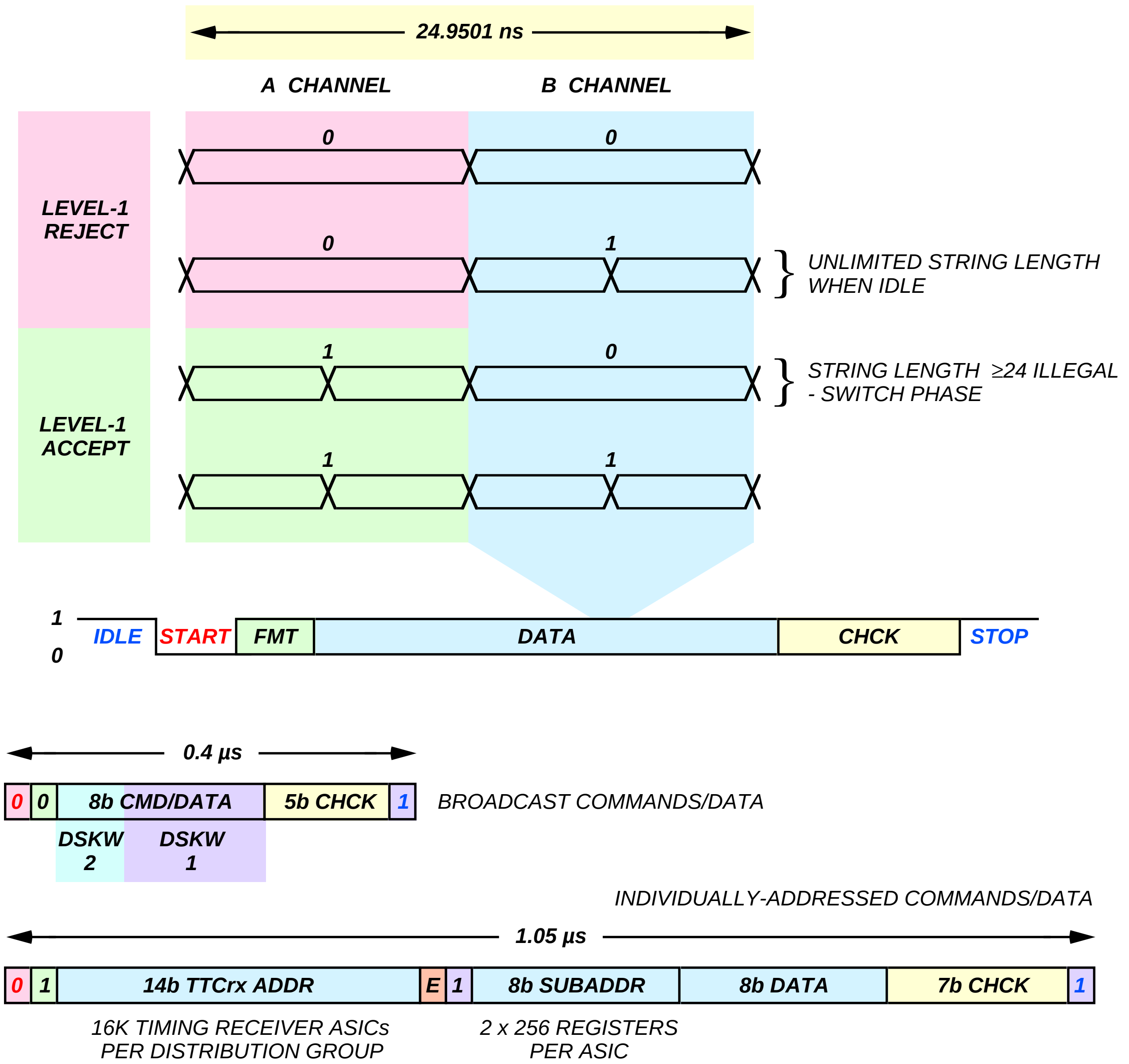
Main optical fibre links



TTC encoding and format



2 TDM channels
No deadtime for commands and data

Biphase mark encoding
Balanced signalling, phase-stable extracted clock

Minimum trigger latency
No control header intercept delay

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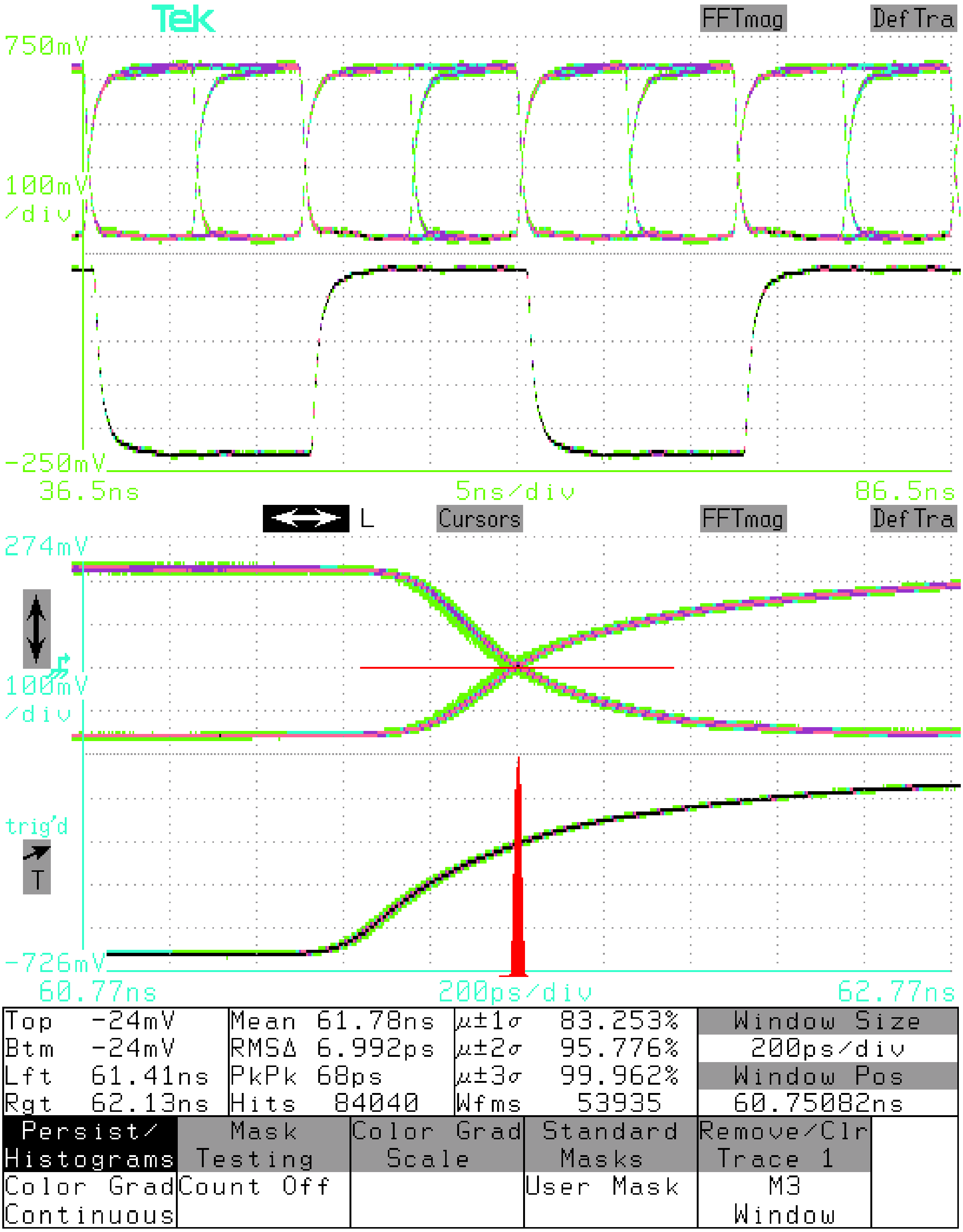
Primary PLL + 160.32 MBaud TDM BM encoder jitter (PRBS data)



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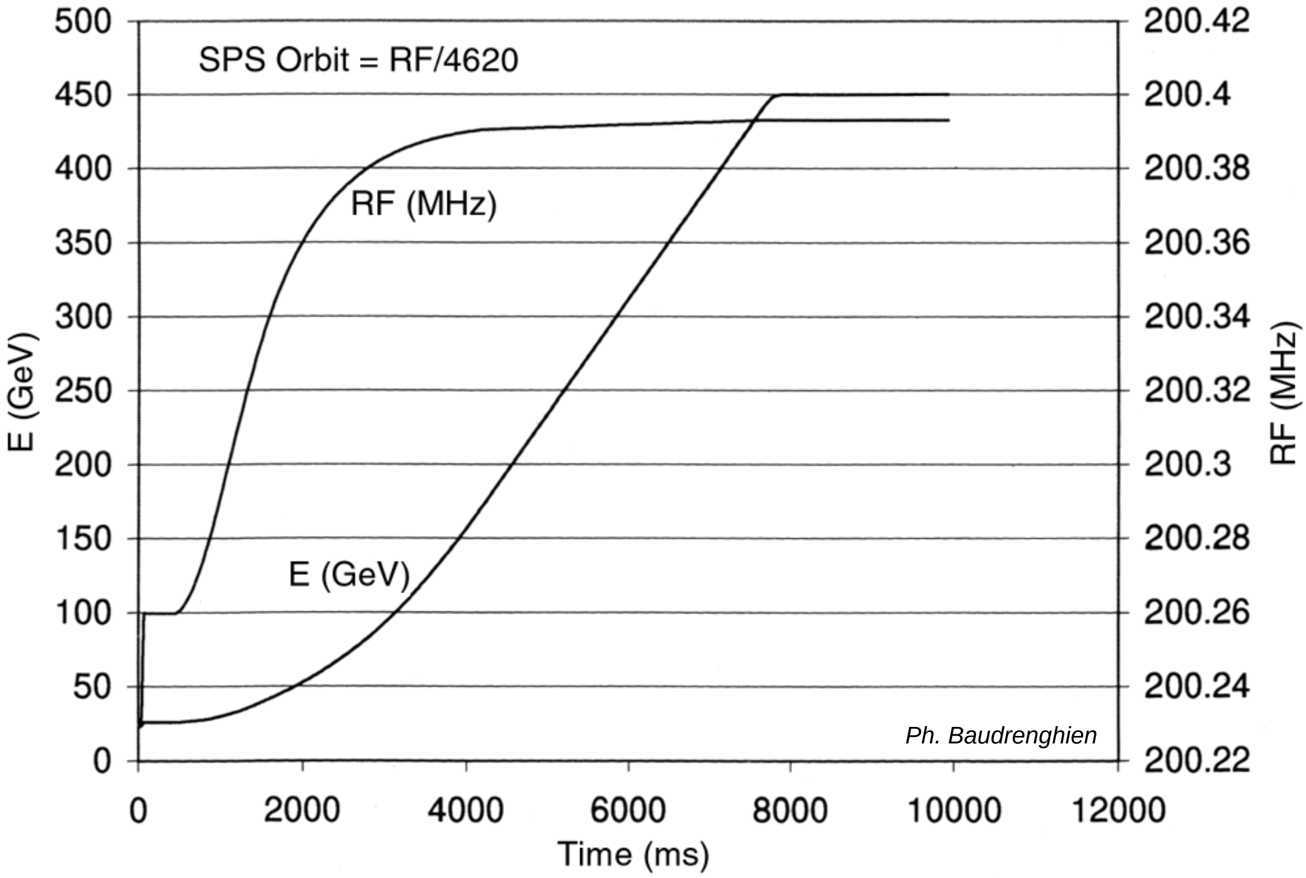
LHC-structured test beams



Constant 40.079 MHz bunch clock

SPS rephased before extraction
- as for LHC injection

"Real" 43 kHz SPS orbit signal
- swings 29 Hz during acceleration

Synchronizer quantizes in 25 ns steps

No metastable glitches

TTC machine interface (TTCmi) crates

```
         110   CERN SL
SPS-Protons  updated: 22-05-00  17:49:29
CYCLE Type 529: 450 Gev/c
      Flat top: 2010 ms  length: 14.4 s
RATE*E11:
  37   17.2             15.9
 CPS   RAMP              SSE
                     to beam dump:   1.3
Targ p/pE11 Mul %Sym Expmt Singles Spill
  T1      3.9     9 a 52 CMS    2.6E+03     0
                         LHCb   4.3E+02     0
  T2      4.1     9 a 78 NA59   0.0E+00     0
                         CMS    6.5E+02     0
  T4      6.5     9 a 87 ATLAS  0.0E+00     0
  T6      0.1    13     0 NA58  0.0E+00     0
  T10     0.0            none   0.0E+00     0

Comments  22-05-00 14:47h  :

EA:CRN operator: 75566 / 160137
```

ALICE

Lab

1 TTCmi + Spare

ATLAS

H8 (North area)

SCT (+ Pixels + TRT)
+ TileCal Oct 2001

1 TTCmi + Spare

CMS

X5 (West area)

Tracker

Upgraded minicrate

H2 (North area)

Muon-RPC (+ HCAL)

1 TTCmi

-> GIF for Oct 2001

H4 (North area)

HF (+ ECAL)

1 TTCmi

LHCb

X7 (West area)

Calorimeter (+ Vertex)

1 TTCmi + Spare

RD12

Lab (Meyrin)

1 TTCmi

SL/BI

Lab (Prevessin)

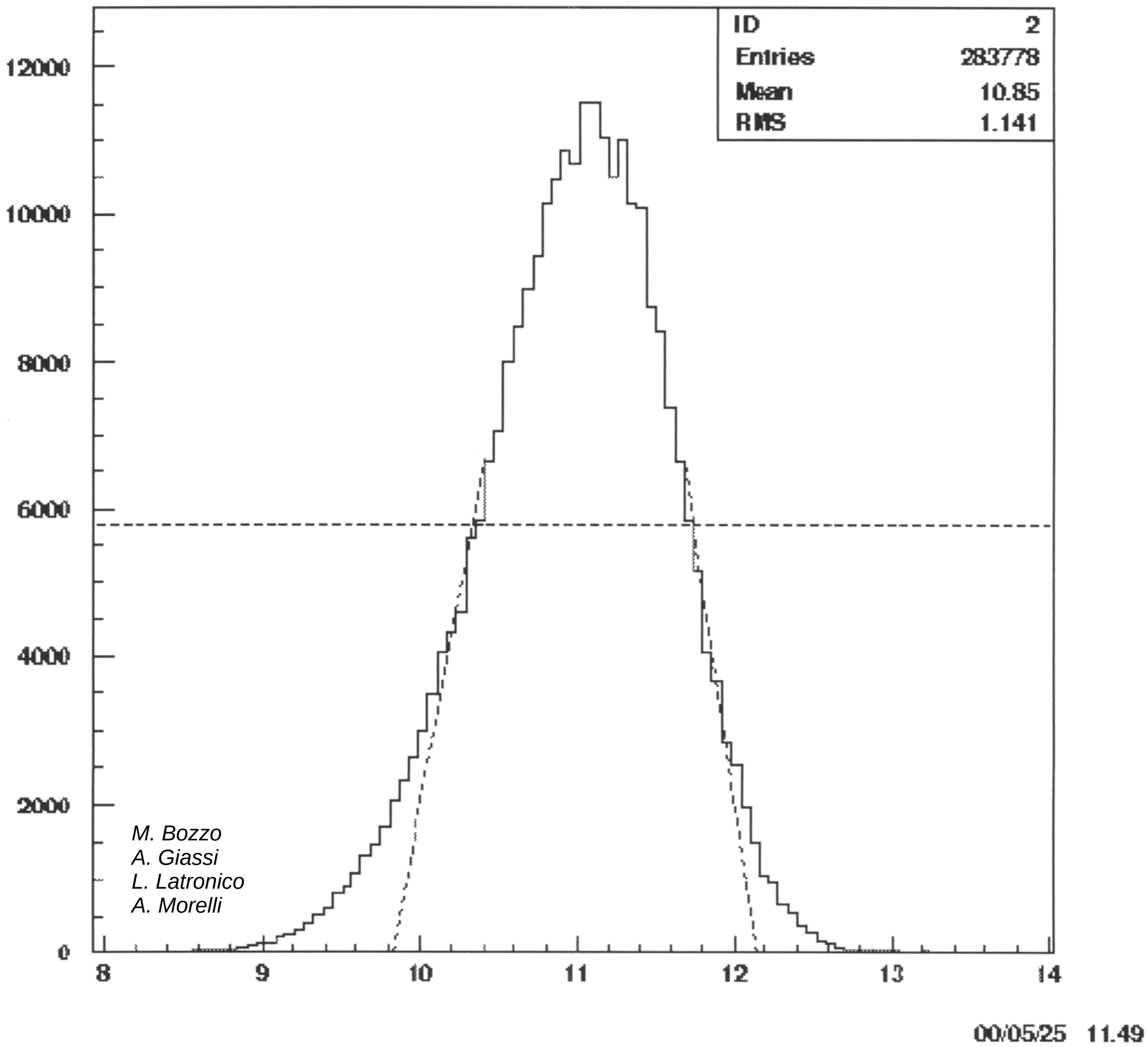
2 reduced TTCmi

ESS

Lab (Meyrin)

1 reduced TTCmi

X5 test beam monitor



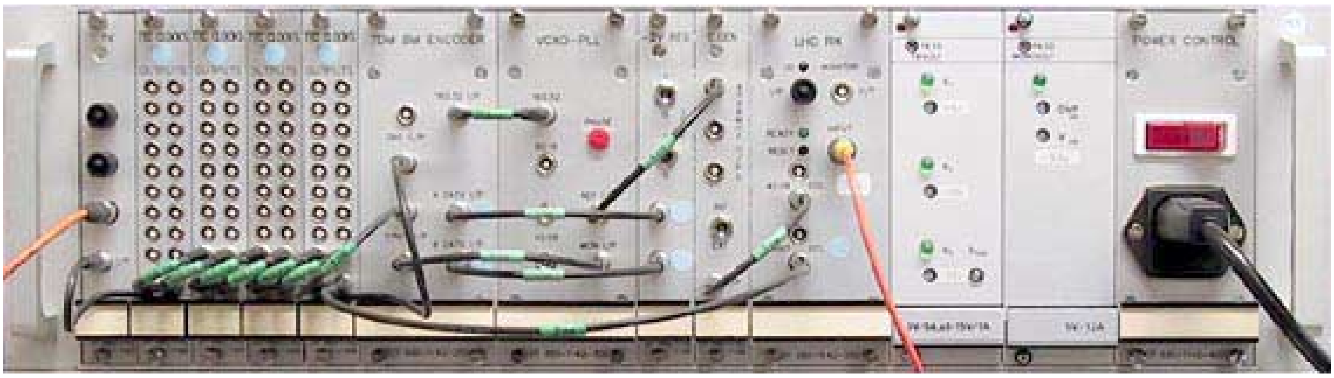
Muon arrival time w.r.t. TTCmi bunch clock

~10^4 μ/spill (2 s spill)

Expected bunch length 2.5 ns

Measured 2.3 ns

TTC machine interface (TTCmi)



Standardised TTC interface to LHC machine

Clock distribution to up to 40 trigger partitions

PLL cleanup of recovered 40.08 MHz clock

Orbit phase adjust 25 ns x 3564

Local clock generator and monitor Rx

Encoder for first partition

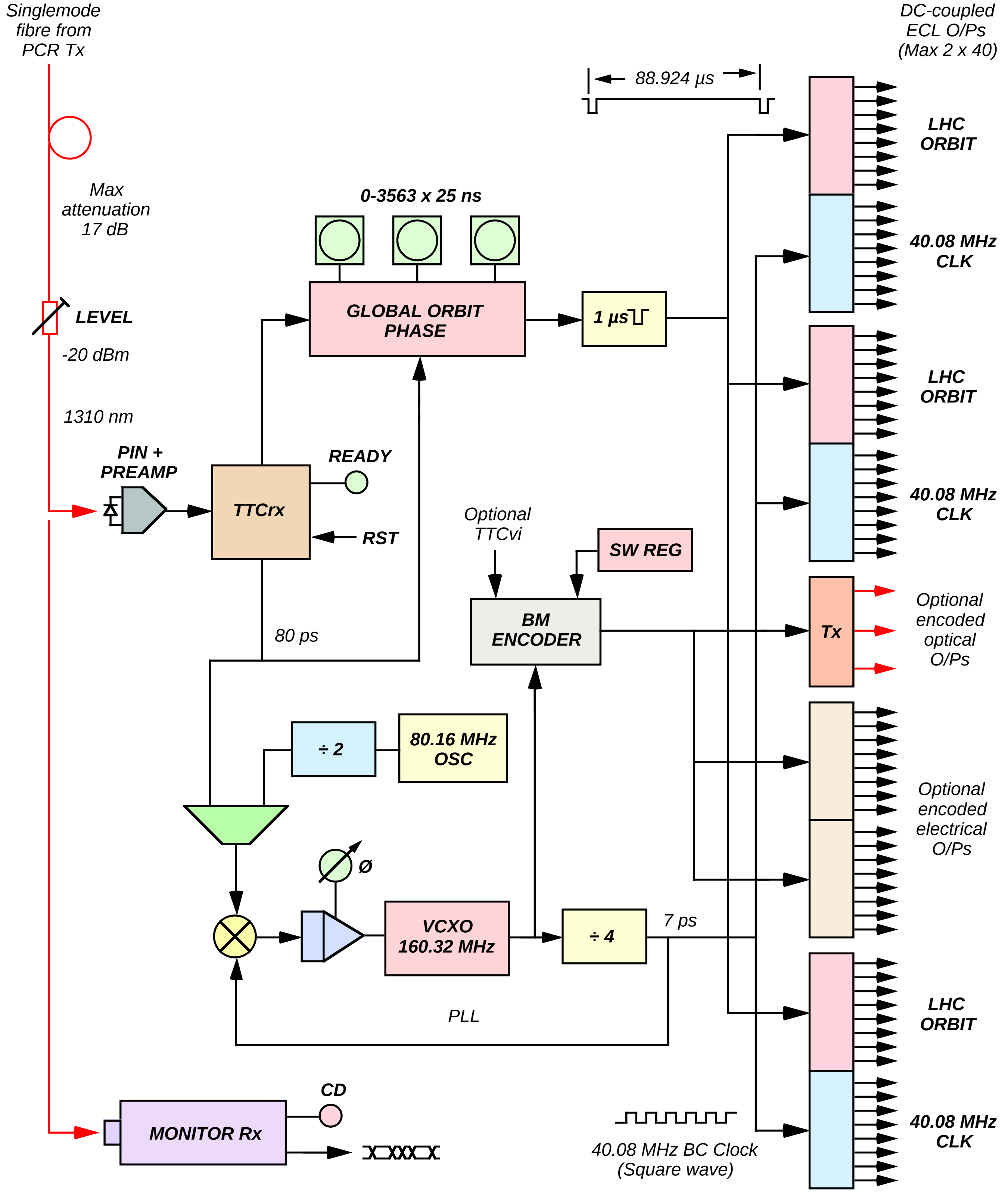
Electrical and/or optical outputs

Easy upgrade from old transmitter minicrates

13 TTCmi produced (Oct 2001)

User Manual on TTC website

TTC machine interface (TTCmi)



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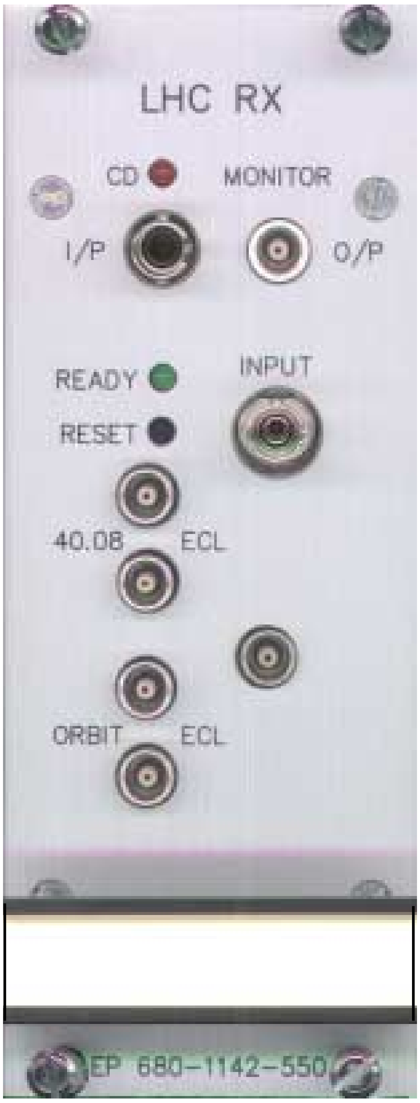
LHC Receiver (LHCrx)



Receives optical timing signals:

from SR4 at PCR

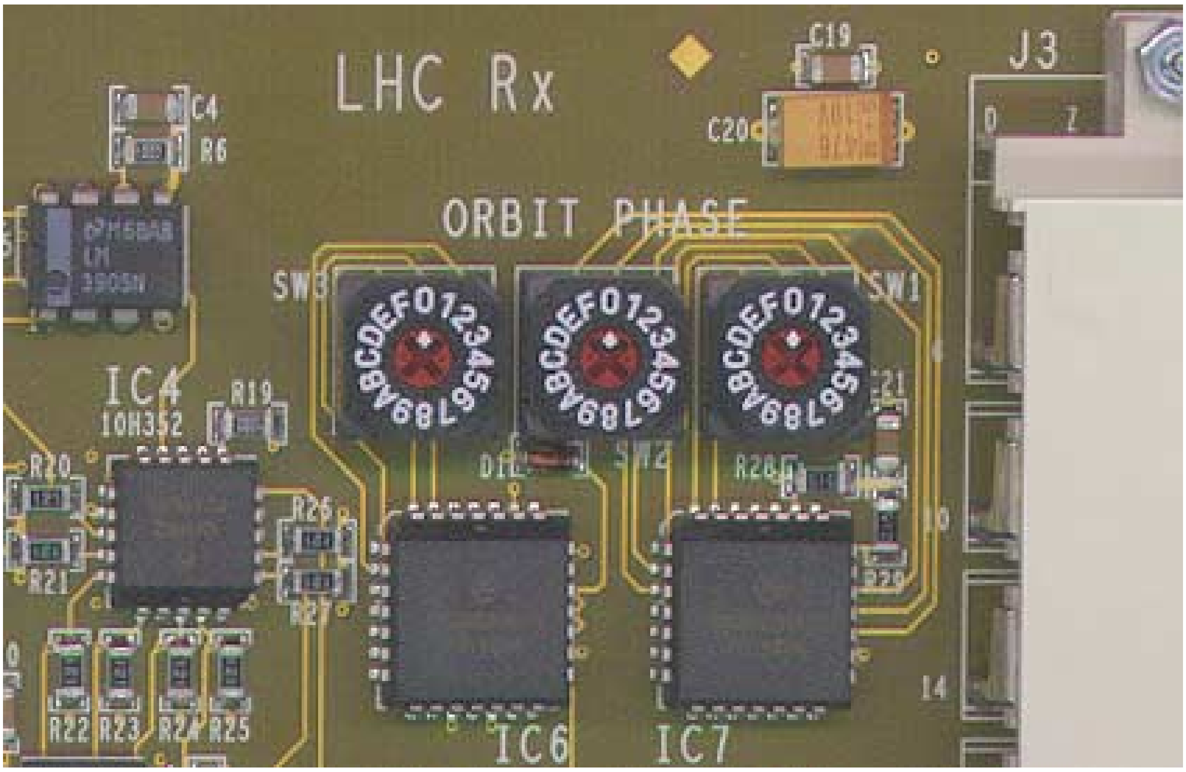
from PCR at LHC experiments and testbeams

Global orbit phase adjust 25 ns x 3564

Monitor function

20 with TTCrx 3.2 ASICs + 2 with 3.1

Orbit phase adjustment



Compensation for location around LHC ring

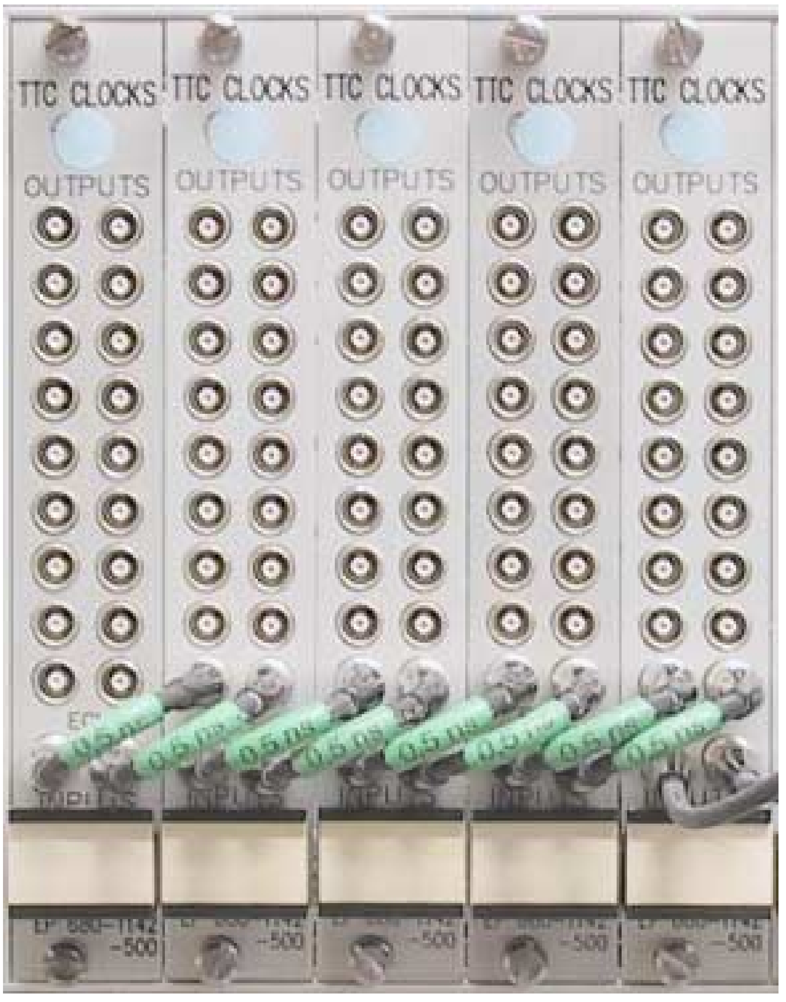
Digital adjuster driven by 40.079 MHz clock

SW1	25 ns steps
SW2	16x25 = 400 ns steps
SW3	16x0.4 = 6.4 µs steps

One-time setup by BPTX monitor sum signals

Adjust phase within TTCrx deskew range (16 BC)

TTC clocks fanout (TTCcf)



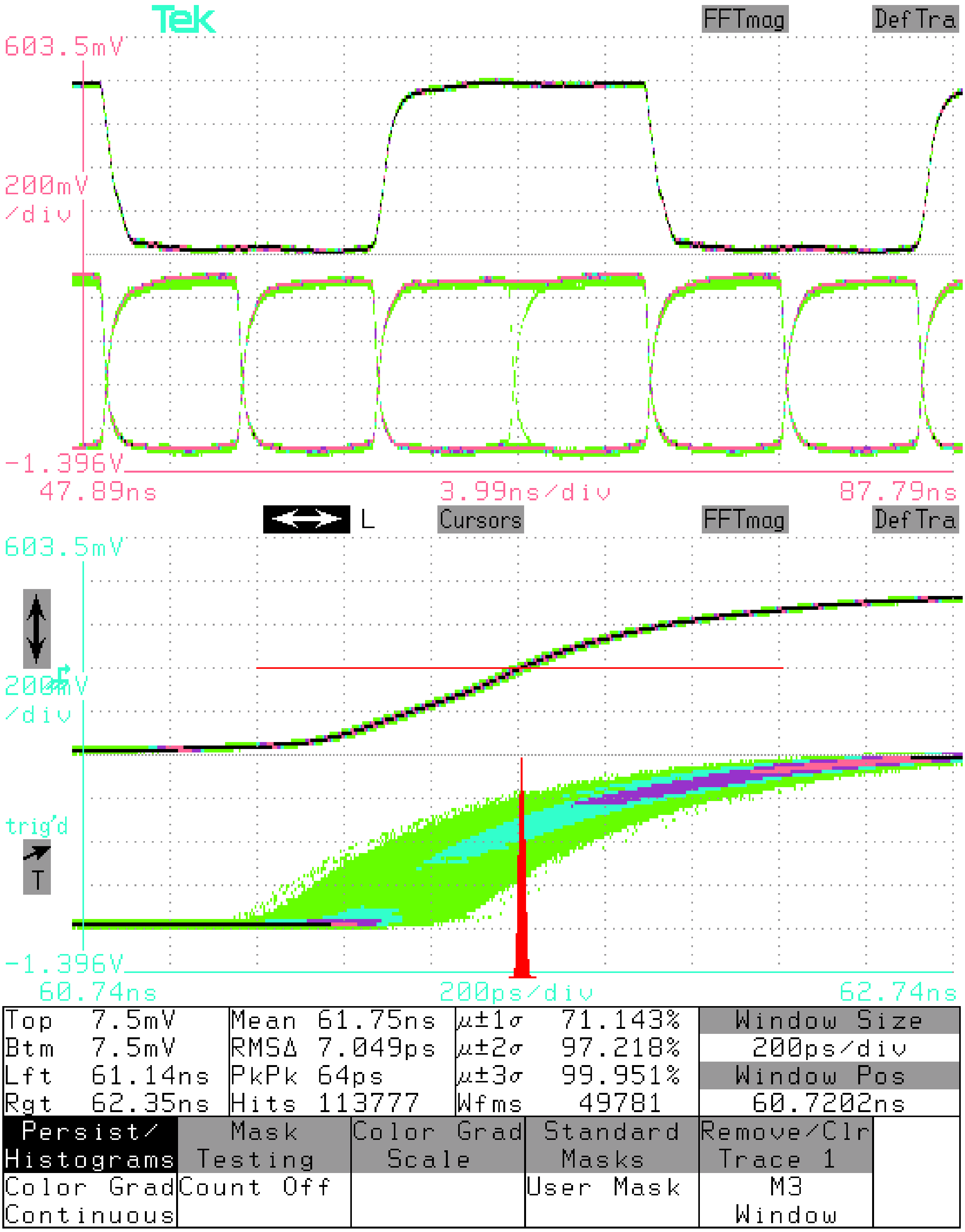
Low-jitter ECL bunch and orbit clocks

Coax fanout to TTCex and TTCvi modules

Up to 2 x 40 outputs per TTCmi

36 produced

TTCmi performance (13 km)



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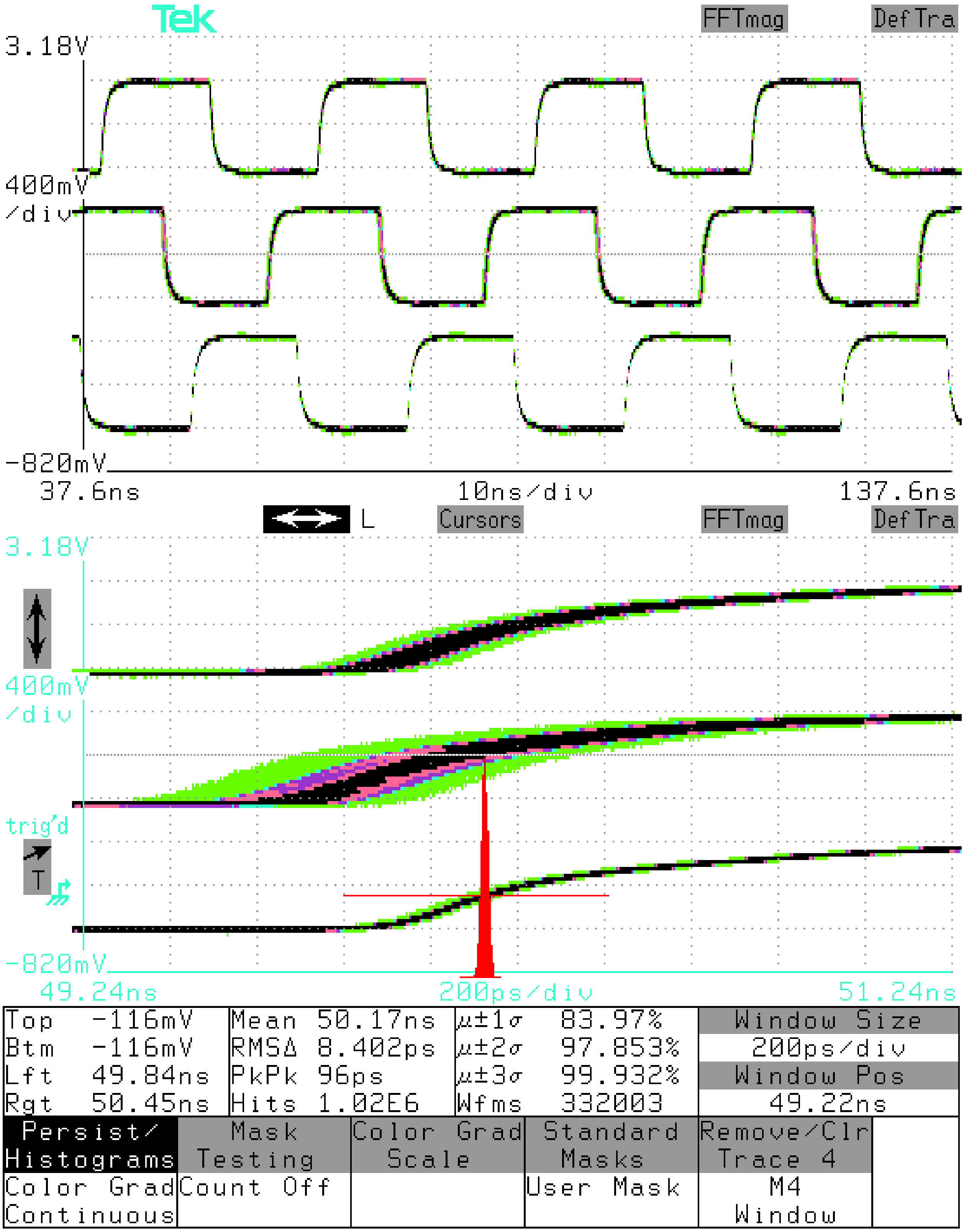
PLL stability check - independent clock link



Zero phase slips in testing for several days

TTC VMEbus interface (TTCvi)

Clock selector	*External or internal*
Orbit selector	*External or Clock/3564*
Trigger selector	*External triggers* *VME trigger* *Random trigger generator* *Calibration trigger*
Commands/data	*Broadcast or individually addressed* *Short or long format*
Async cmnds/data	*On VME write or external signals* *On L1A: Trigger type from CTP +* *Event/Orbit No. from 24-bit counter*
Sync commands	*4 chans with priority arbitration* *External or VME B-Go* *Prog inhibit delay and duration* *256 FIFO per channel* *Single/sequence/repetitive (BCR)* *Burst mode for BI use*

User manual on TTC website

TTC VMEbus interface (TTCvi)

Only one failure in 4 years

Questionnaire to 60 users

Upgraded to Mk II + BI mods

40 Mk I + 43 Mk II produced at CERN

80 modules ordered from EFACEC (PT)

TTC laser transmitter (TTCtx)

Compact module for experiments

1 or 2 partitions per module

Configurable 32 to 448 destinations

Daisy chain expansion

Temp-compensated bias/modulation

Rear facet automatic power control

SYSFAIL interlock

Standard (+5v) VMEbus power

User manual on TTC website

Per crate -

8960 destinations

1 to 40 partitions

B.G. Taylor 00.07.07

TTC laser encoder/transmitter (TTCex)

Dual encoders

Common VCXO/PLL

1 or 2 partitions per module

Configurable 32 to 320 destinations

Expansion by TTCtx modules

Temp-compensated bias/modulation

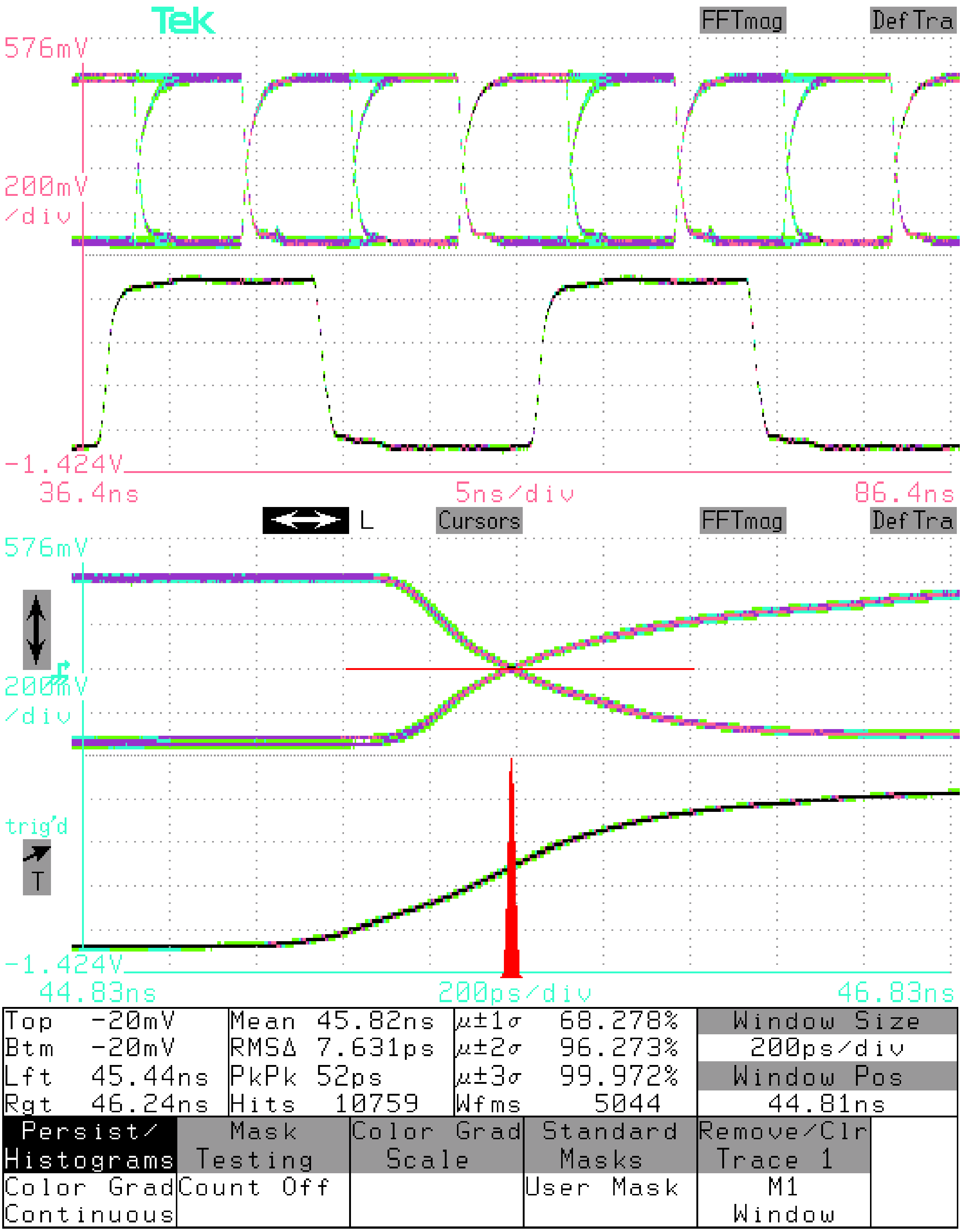
Rear facet automatic power control

SYSFAIL interlock

Standard (±12v, +5v) VMEbus power

User manual on TTC website

TTCex encoder jitter (PRBS data)



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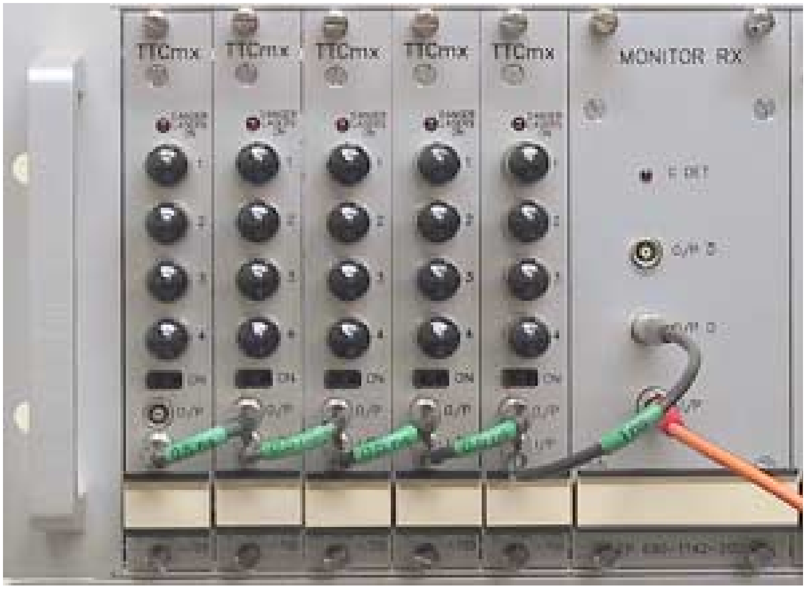
TTC laser mini-transmitter (TTCmx)

- Laser output for TTCmi or repeaters
- Configurable 32 to 128 destinations
- Daisy chain expansion x 5 modules
- Temp-compensated bias/modulation
- Rear facet automatic power control
- Interlock provision
- Standard (+5v) minicrate power
- User manual on TTC website



- Inexpensive minicrate with 5v power only
- Receives optical TTC signal from PCR
- Repeater re-broadcasts without decoding
- 40 crates for LHC machine (8 in SPS for 2002)

Laser TTC transmitters

2000/2001

COMPASS - TTCtx

ALICE - TTCex, TTCmx

ATLAS - TTCex, TTCmx

CMS - TTCex, TTCmx

LHCb - TTCtx, TTCmx

RD12 - TTCex, TTCtx, TTCmx

SL/BI - TTCmx

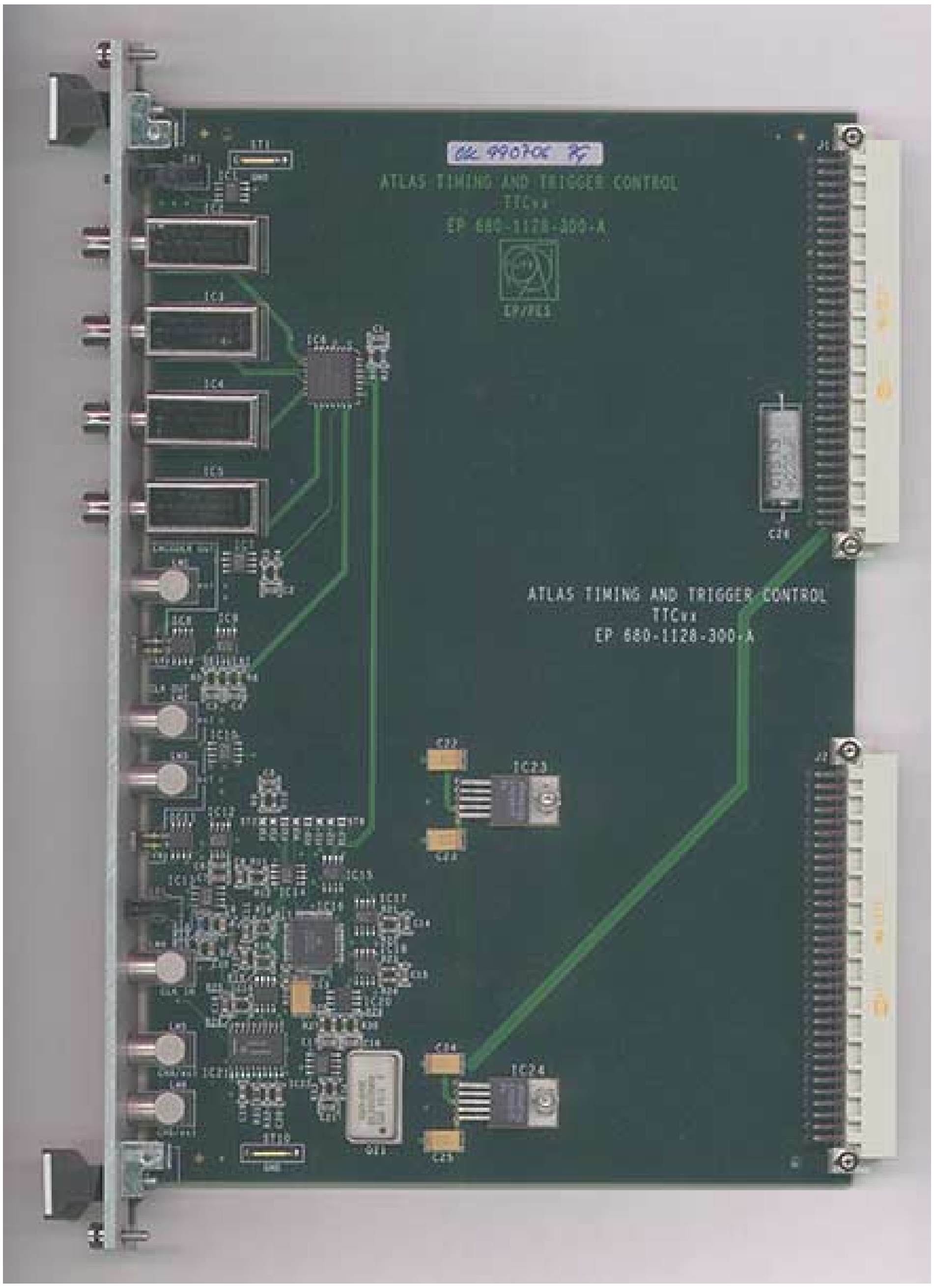
SL/CO - TTCtx

EP/ESS - TTCex, TTCtx

2002 requests

TTCex	18
TTCtx	4
TTCmx	8

TTCvx LED transmitter



Low-power module for development work

Up to 4 destinations

TTC optical tree couplers

FBT technology

Coupling loss (1x32) 15.1 dB

MM TTCoc for experiments (single fusion)

Excess loss 2 dB

20 dB attenuator
for tests

SM for PCR (cascaded 1x2, 1x4, 1x4)

Excess loss (1x32) 4 dB

Latency

Transmitter - receiver channel

(A input of Tx to TTCrx L1A O/P)

TTCex: 68 ns + fibre

TTCtx (1 ns from TTCex encoder): 73 ns + fibre

TTCmx (1 ns from TTCmi encoder): 61 ns + fibre

- with internal TTCrx deskews set to minimum!

Daisy chaining

TTCtx: 2 ns + 0.5 ns coax

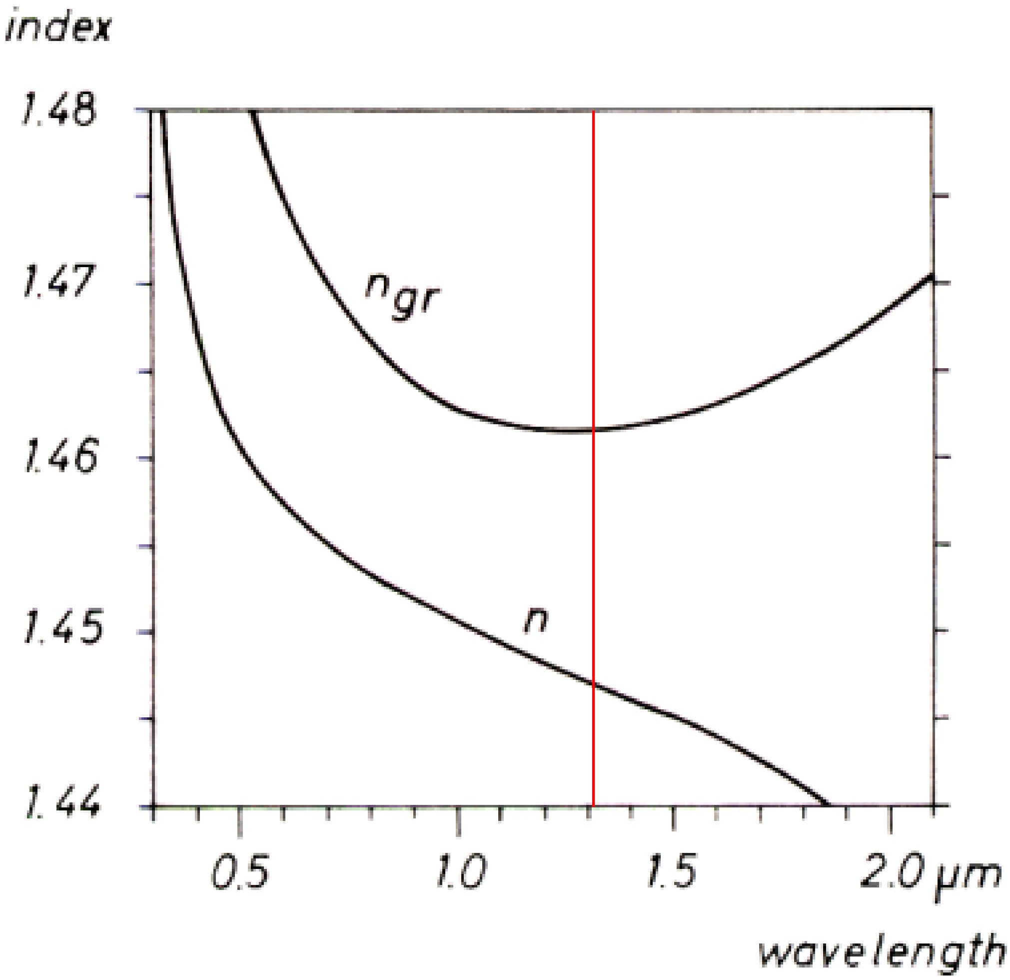
TTCmx: 1.5 ns + 0.5 ns coax

Fibre

4.9 ns/m at 1310 nm

TTCoc: 5.7 ns (11 ns earlier version)

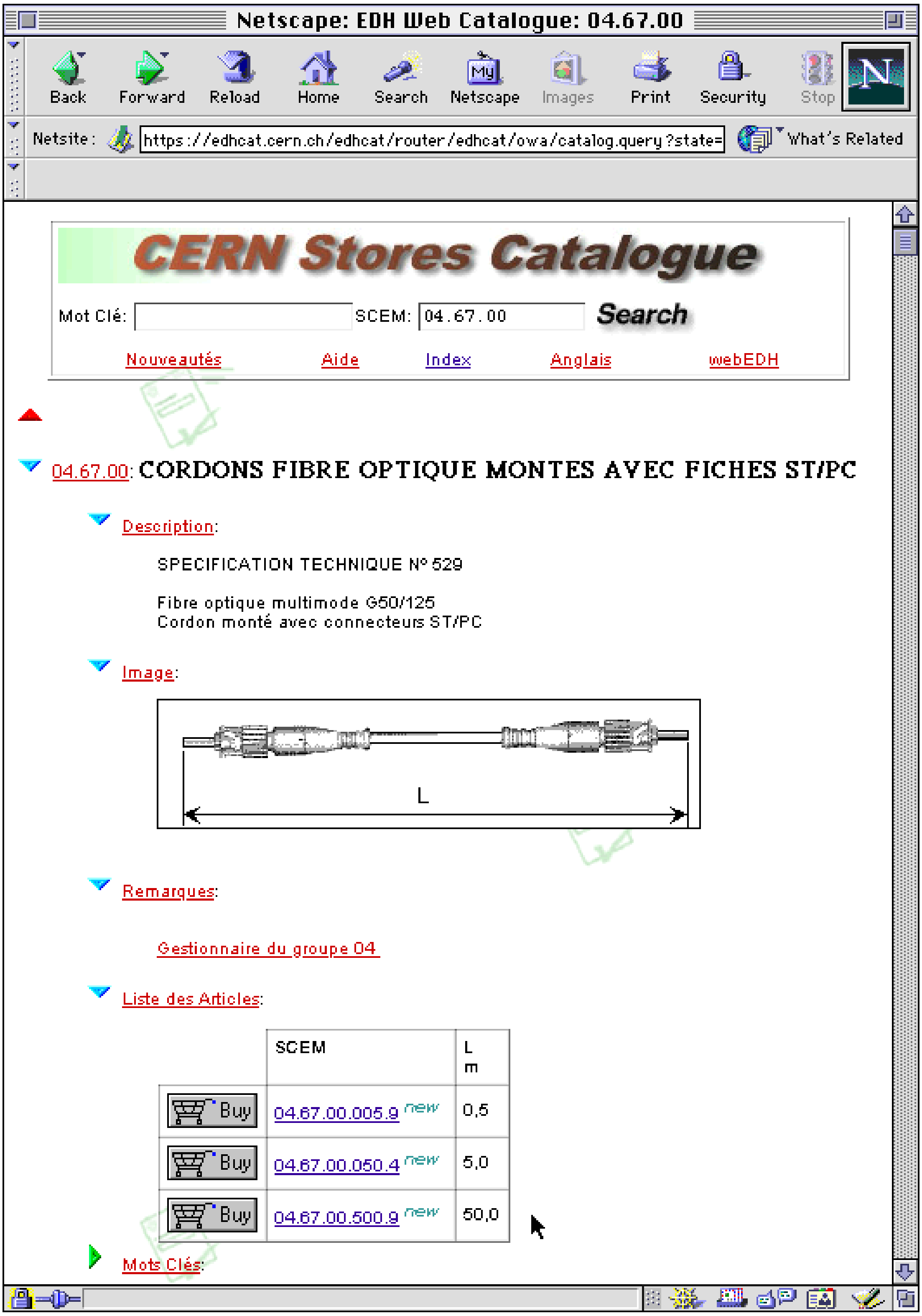
Group velocity



Group index n_{gr} = $(n - \lambda dn/d\lambda)$ = 1.462 @ 1310 nm
Group velocity factor = $1/n_{gr}$

	Velocity factor	100m delay
Solid dielectric coax	0.66	505 ns
Optical fibre 1310 nm	0.68	490 ns
Small dia. cellular coax	0.69	484 ns
Large dia. cellular coax	0.82	407 ns

TTC optical patchcords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Mot Clé: SCEM: 04.67.00 Search

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04.67.00: CORDONS FIBRE OPTIQUE MONTES AVEC FICHES ST/PC

Description:

SPECIFICATION TECHNIQUE N° 529

Fibre optique multimode G50/125
Cordon monté avec connecteurs ST/PC

Image:

L

Remarques:

Gestionnaire du groupe 04

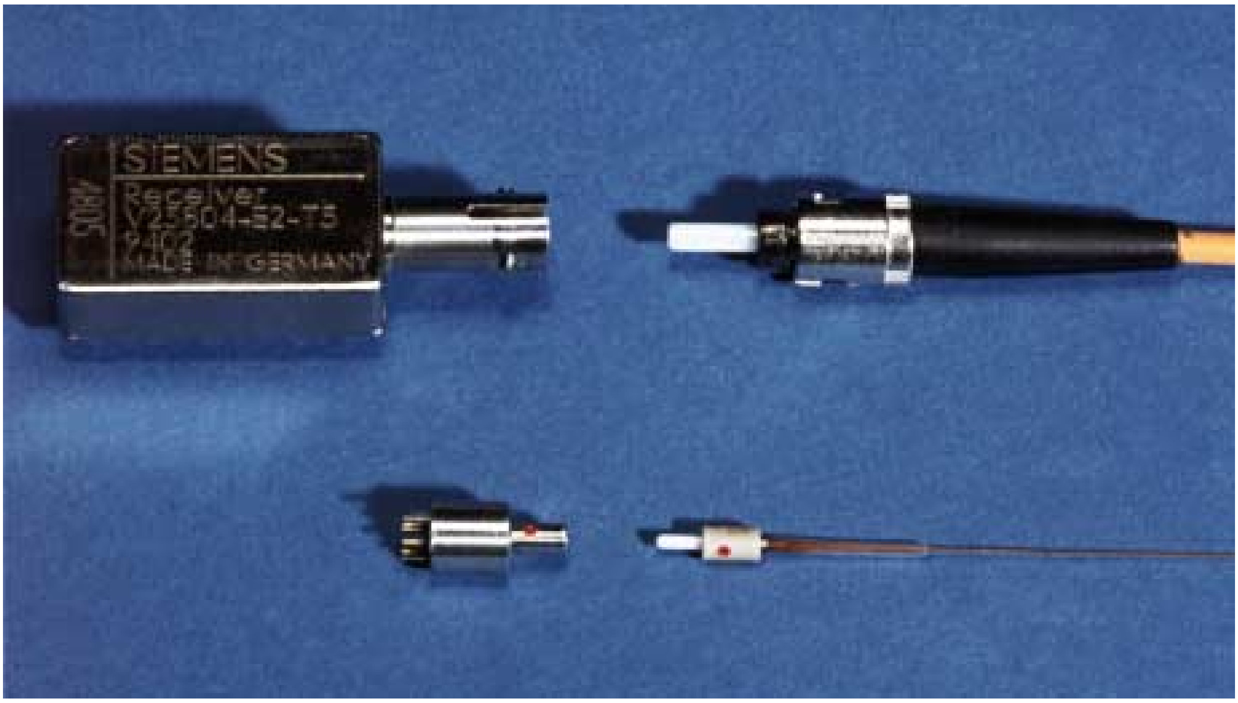
Liste des Articles:

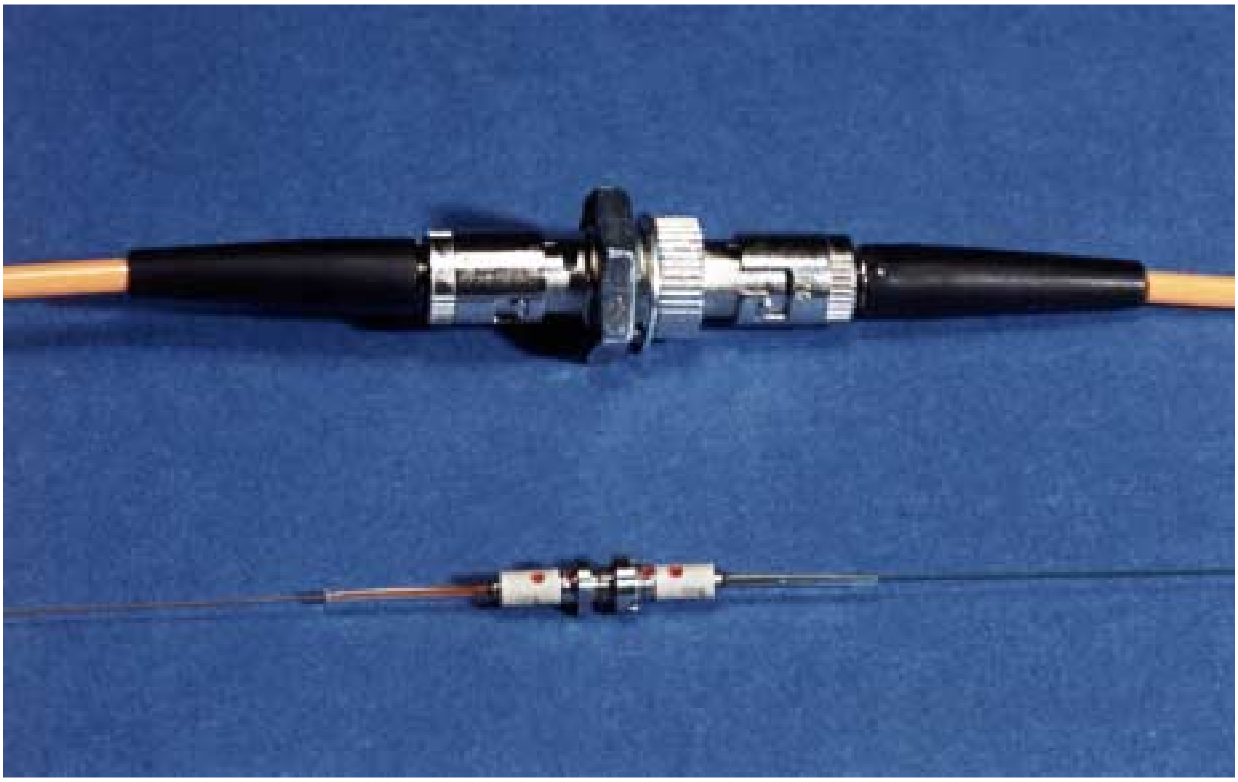
	SCEM	L m
Buy	04.67.00.005.9 new	0,5
Buy	04.67.00.050.4 new	5,0
Buy	04.67.00.500.9 new	50,0

Mots Clés:

0.5m, 1.5m, 5m, 15m, 50m stocked

Subminiature optical connector





Boeing + helicopter tests passed

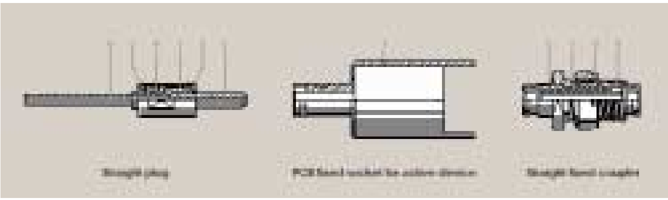
Transferred to Ecublens

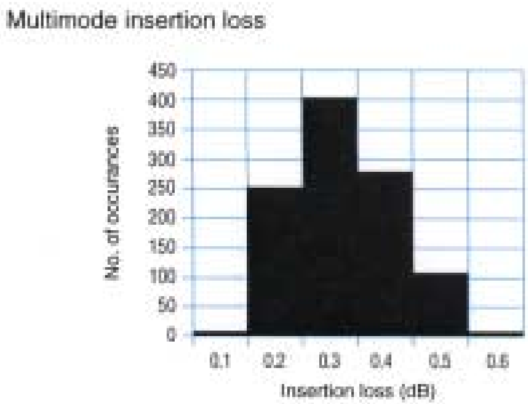
B.G. Taylor 01.06.05

RD12 connector

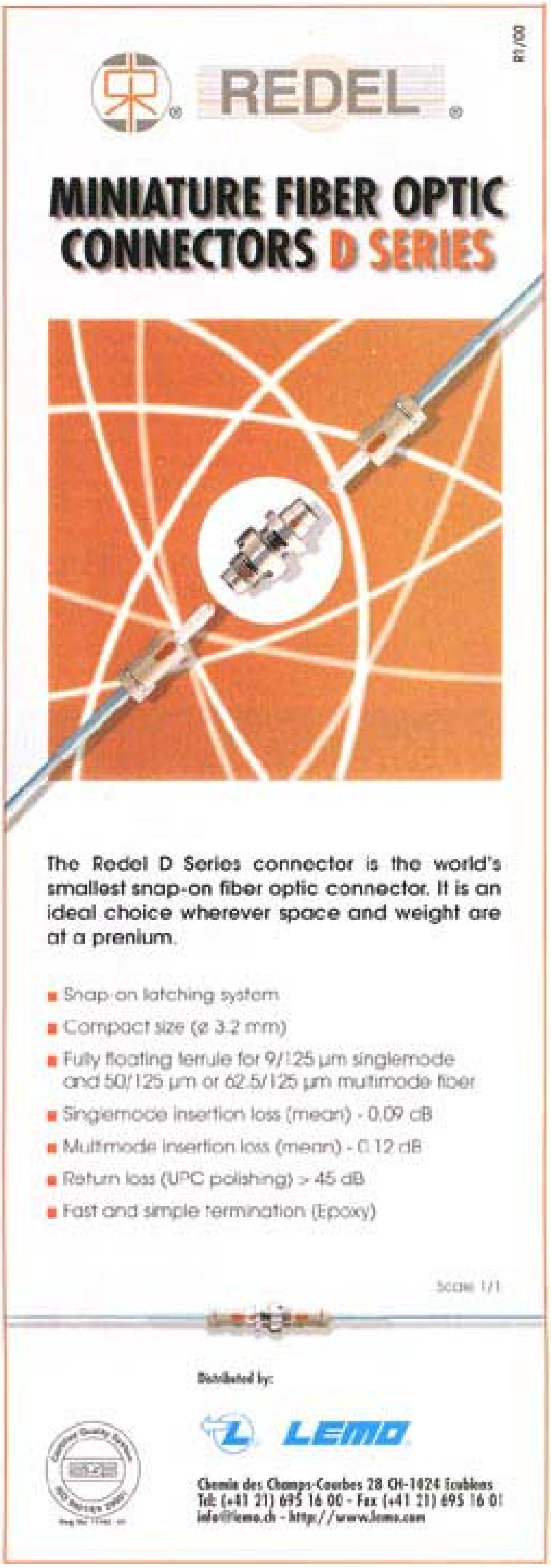
"The world's smallest snap-on fiber optic connector"

- Lemo SA





Std Deviation = 0.09 dB
Mean = 0.27 dB
Fibre = 50/125 µm



http://www.lemo.ch

TTC optoelectronic receivers

Agilent HFBR-2316T

InGaAs PIN diode

Si bipolar preamp

TrueLight TRR-1B43-000

InGaAs PIN diode + AGC preamp

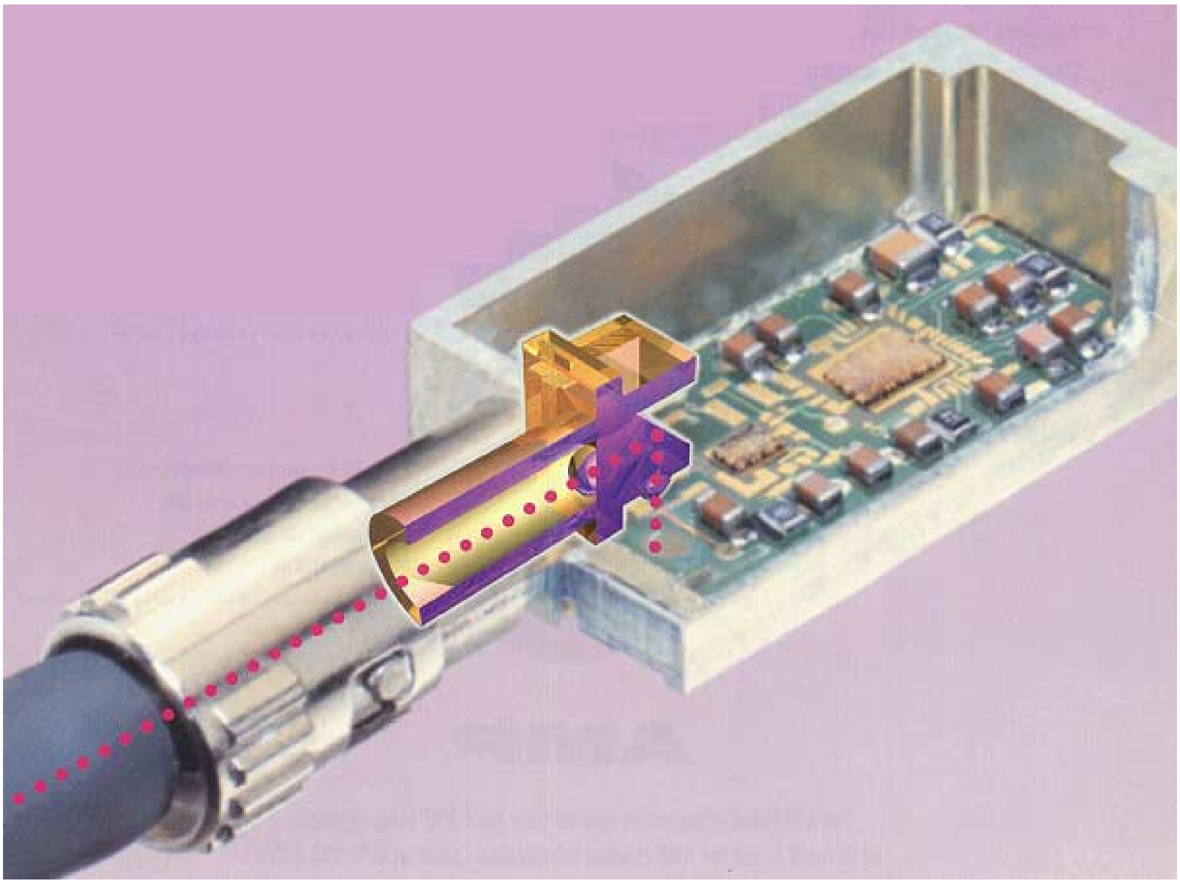
$8 datacom device

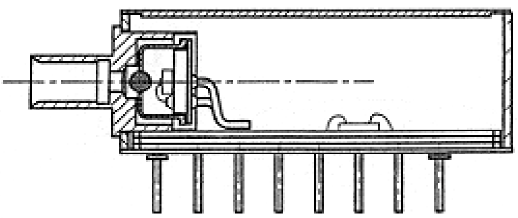
Agilent HFBR-2119T

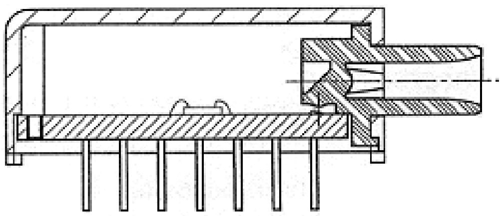
Complete modular receiver

ECL bus for multiple TTCrx

Molded-Optronic technology





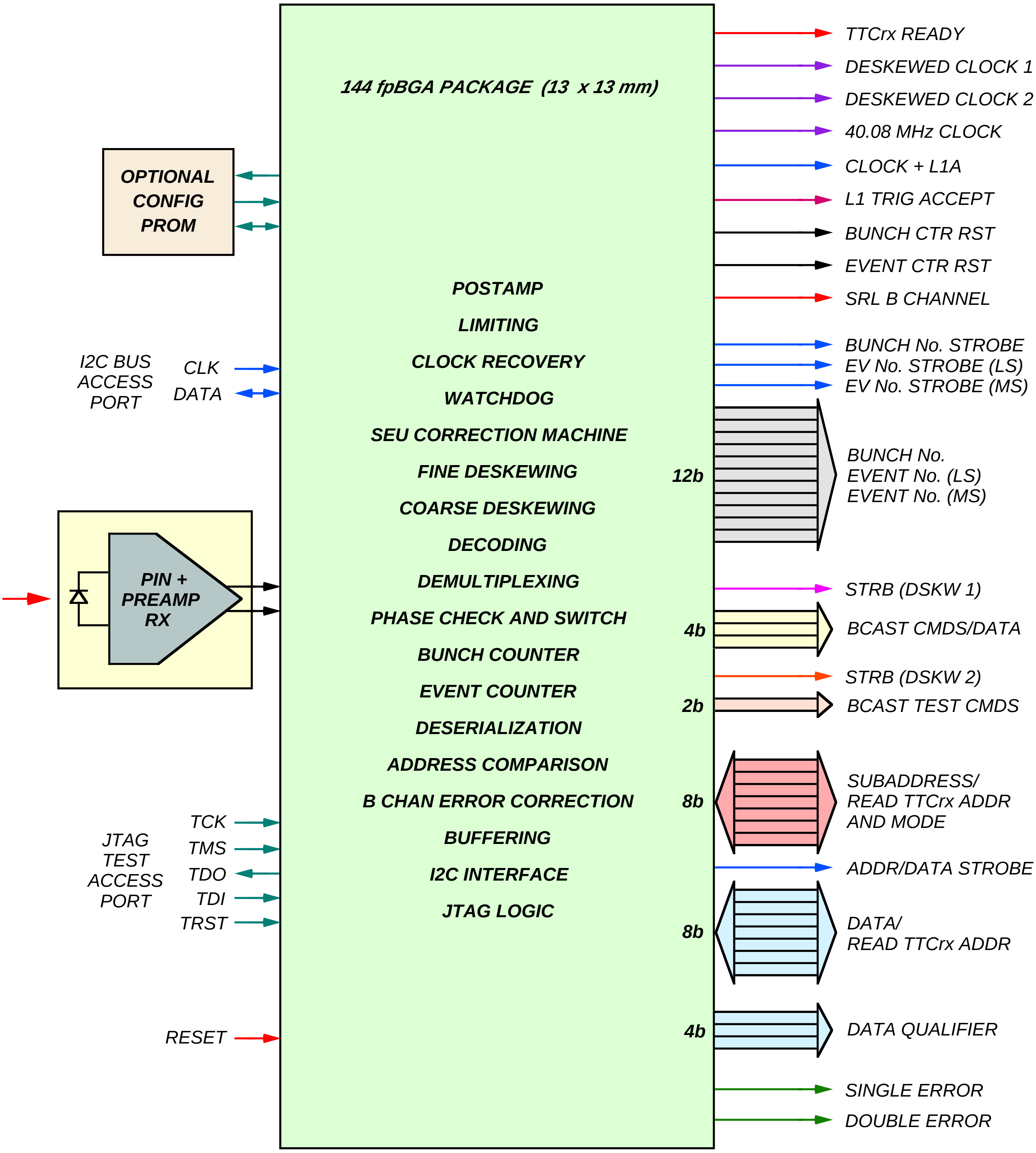


Integrated lens/receptacle

Alignment, light coupling and bending

Reduced parts count and assembly cost

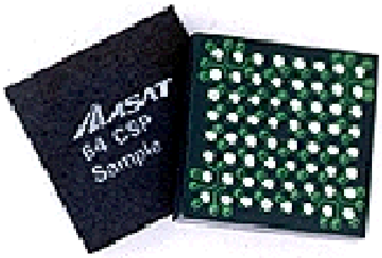
TTC timing receiver ASIC (TTCrx)



Rev. 3 (DMILL) TTCrx

B.G. Taylor 01.01.20

TTCrx development



1 µm ES2 TTCrx

- Remaining 78 BGA samples:
- MIC: 8, PCR+TTCmi: 10,
- LHC experiments: 60

0.8 µm DMILL TTCrx

- 20 received Feb 2000 (some PGA)
- Fully functional. +40 option taken
- Yield ~75%

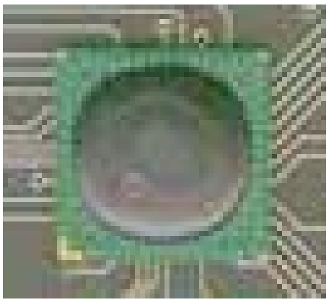
Radiation hardness

- 8 Mrad, 5×10^{13} n and SEU tests
- No degradation of fine deskewing
- No internal SEU problems
- Mod to mitigate photodiode SEU effects

1st Engineering run (ATMEL)

- Split proven (3.1) + modified (3.2) design
- 8 wafers (3200 chips) received Jan 2001
- Yield 81%
- Rev 3.2 also OK

TTCrx packaging

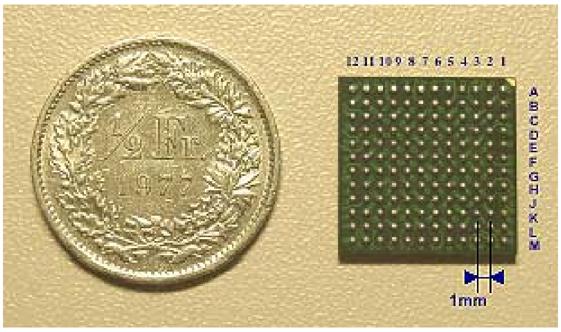


100 BGA

15 x 15 mm, 1.27 mm pitch

IBM Vimercrate $3.9 (10K qty) + $10,000 NRE

-> Celestica $40 (10K qty) + $15,000 NRE

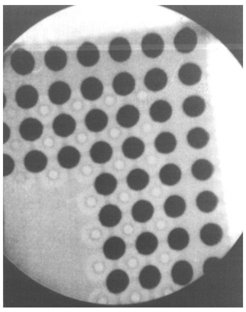


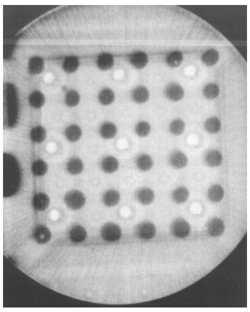
144 fpBGA

ASAT 13 x 13 mm, 1 mm pitch

$1.58 (10K qty) + $0.04 shipping trays

10 days for first assembly lot





Ardelec (F)

100% radiography control

Individually certified

Scolari (CH)

TTCrx development → production

2nd Engineering run

New reticule with Rev 3.2 only

Submitted Aug 2001 (EUR 139K)

ALICE 9%, ATLAS 46%, CMS 36%, LHCb 9%

Delayed by DMILL QC problems

3 wafers February, 7 wafers July 2002

Yield ~80%

Production

Estimated requirements:

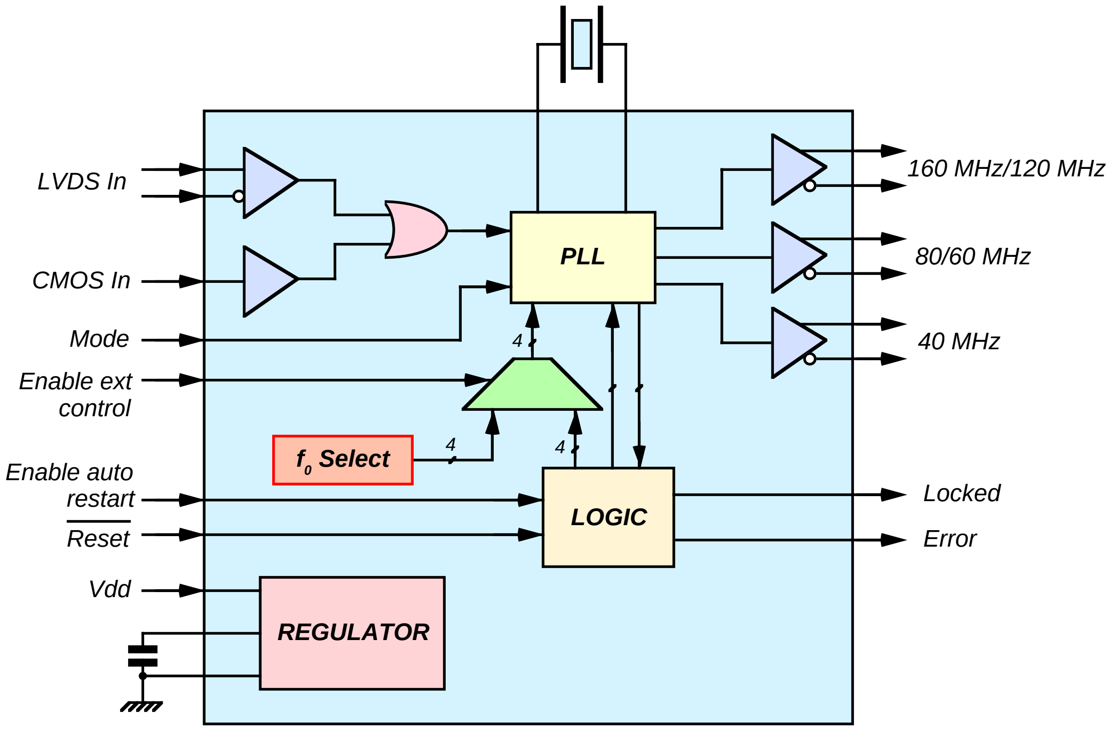
ALICE	1600
ATLAS	8500
CMS	7000
LHCb	1600
Totem	500
LHC machine	600
	19800

50 wafers, 70% yield = 22316 good chips

CHF 467K + CHF 110K packaging & testing

Order October 2002 – Delivery May 2003

QPLL auxiliary chip



VCXO/PLL jitter filter for TTCrx

Rad-tolerant 0.25 µm CMOS

3 LVDS clock outputs

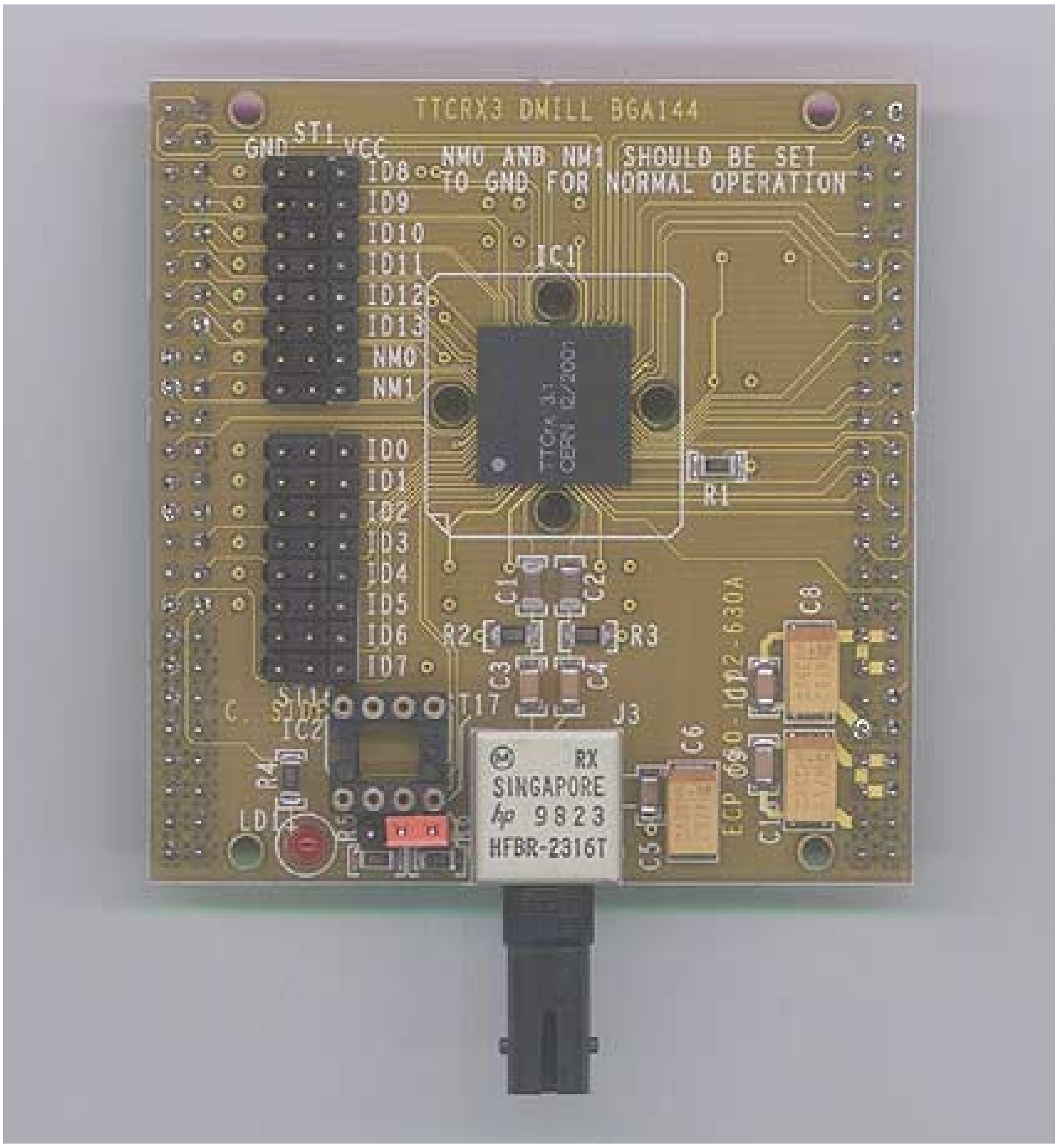
2 frequency multiplication modes

4 mm x 4 mm LPCC-24 package

MPW submission 3Q02

B.G. Taylor 02.09.04

Mezzanine TTCrx test board (TTCrm)



Convenient carrier for initial tests or evaluation

Current version for DMILL 144 fpBGA TTCrx

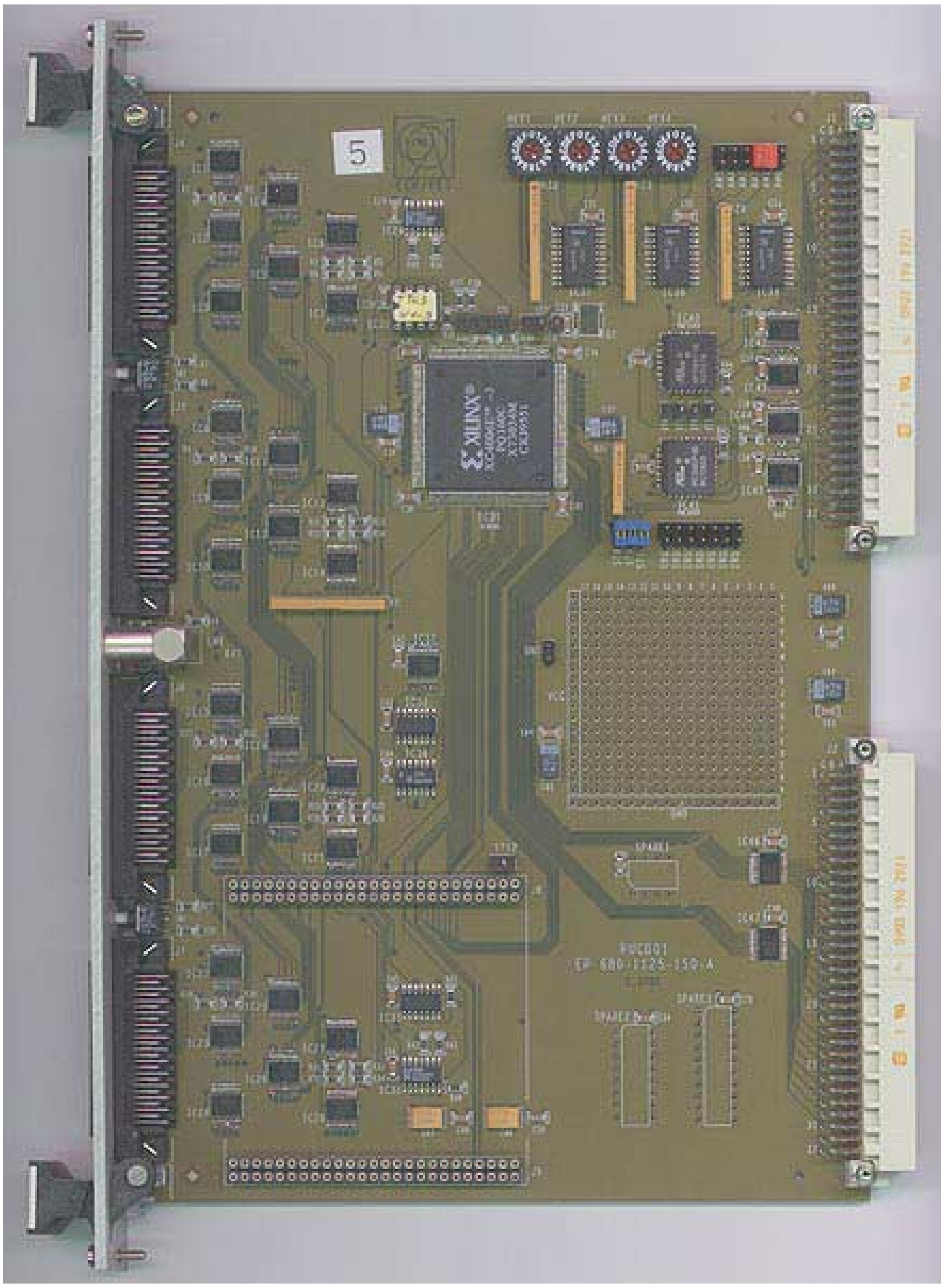
Jumpers for address selection

Requires modification for TRR-1B43-000

New pinout for QPLL version

B.G. Taylor 02.09.04

TTC VME receiver (TTCvr)



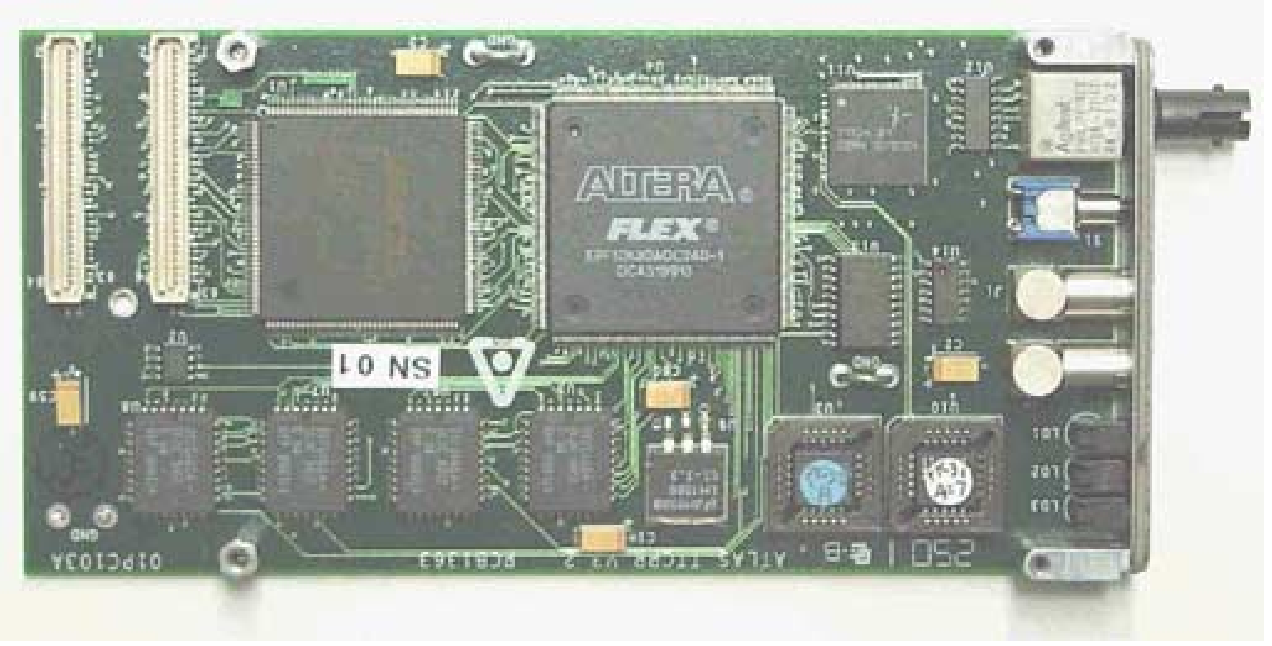
General-purpose VMEmodule

Accepts TTCrm mezzanine

User-programmable Xilinx XC4006E

A24/D32 VME interface and buffers

TTC PMC receiver (TTCpr)



Developed by ANL

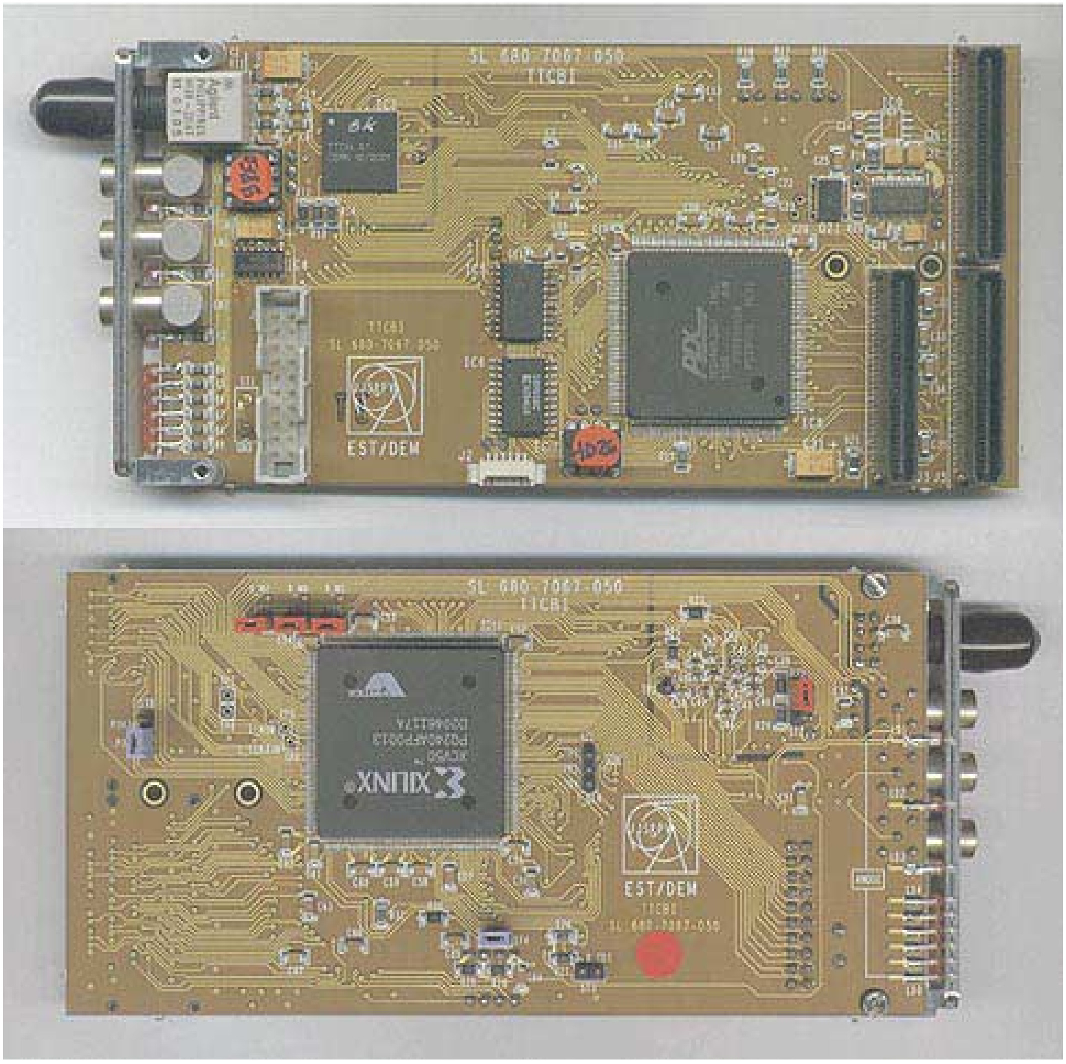
PMC for ATLAS tile calorimeter DAQ
(available to other groups)

User-programmable Altera 10K30A

4 blocks of 8K x 16b FIFO

Mk II version

TTC beam instrumentation interface (TTCbi)



IEEE P1386.1 PMC slave card

Standard BST interface to LHC BI

256 bytes dual-port RAM

Experiments can use to receive LHC machine info

3 protos built.   Mk II in design

SPS tests May - Sept 2002

LynxOS driver

LHC info via TTCbi

Uses B-channel long format broadcast from PCR Tx

LHC machine events

e.g. Start ramp

Dump

Post mortem

LHC status messages

Part of 32-byte BST messages

e.g. Mode (Filling, adjusting, ramping, physics)

Beam type

Mean current per bunch

No. of bunches

Beam energy

GPS-derived UTC time

TTC laser safety

CLASS I LASER PRODUCT
NOTE: UNTERMINATED OPTICAL CONNECTORS MAY EMIT LASER RADIATION.
DO NOT VIEW WITH OPTICAL INSTRUMENTS.

This Product Complies with 21 CFR 1040.10 and 1040.11

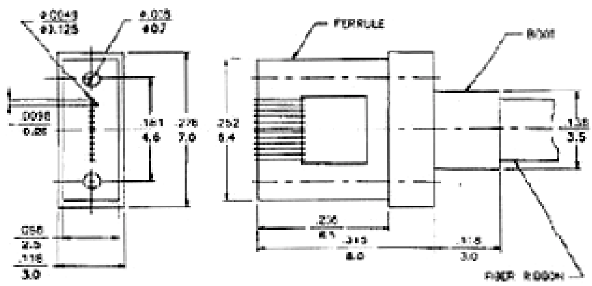
CERN IS 22, CDRH 21CFR1040, IEC 60825

Class 1 after root coupler

1310 nm – 8.8 mW

850 nm – 0.4 mW

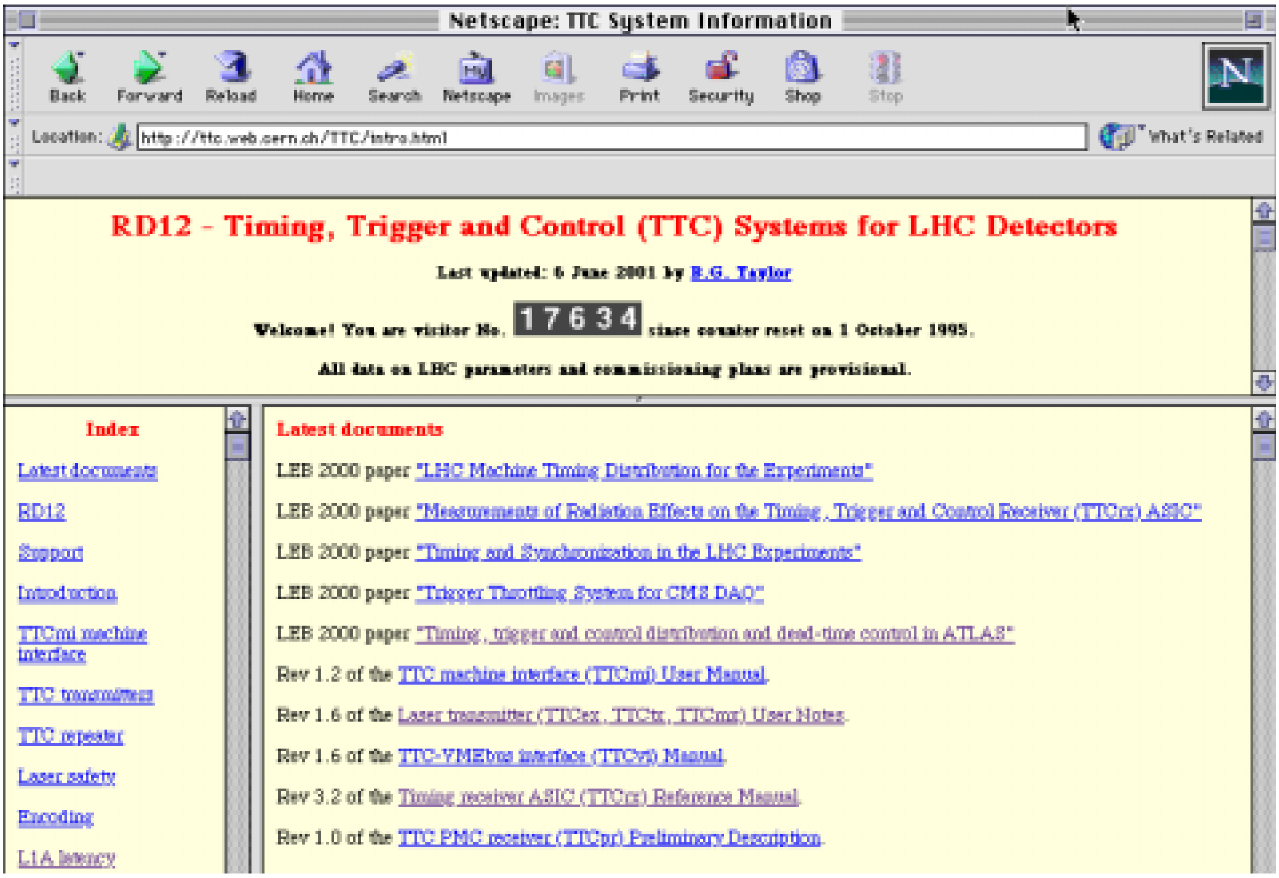
- But no ribbon connectors for Tx outputs!



Class 3B in PCR transmitter racks

- "Controlled access" area

Internet



TTC website

http://www.cern.ch/TTC/intro.html

TTC mailing list

TTC news and information-sharing

RD12 participants available

ListServer@listbox.cern.ch:
subscribe lhc-exp-ttc [email address]

Post to:
lhc-exp-ttc@listbox.cern.ch

Assistance:
owner-lhc-exp-ttc@listbox.cern.ch