LHC Beam Instrumentation & Commissioning

Tune Feedback Workshop

BNL - 9th-11th March 2005

Rhodri Jones (CERN – AB/BDI)

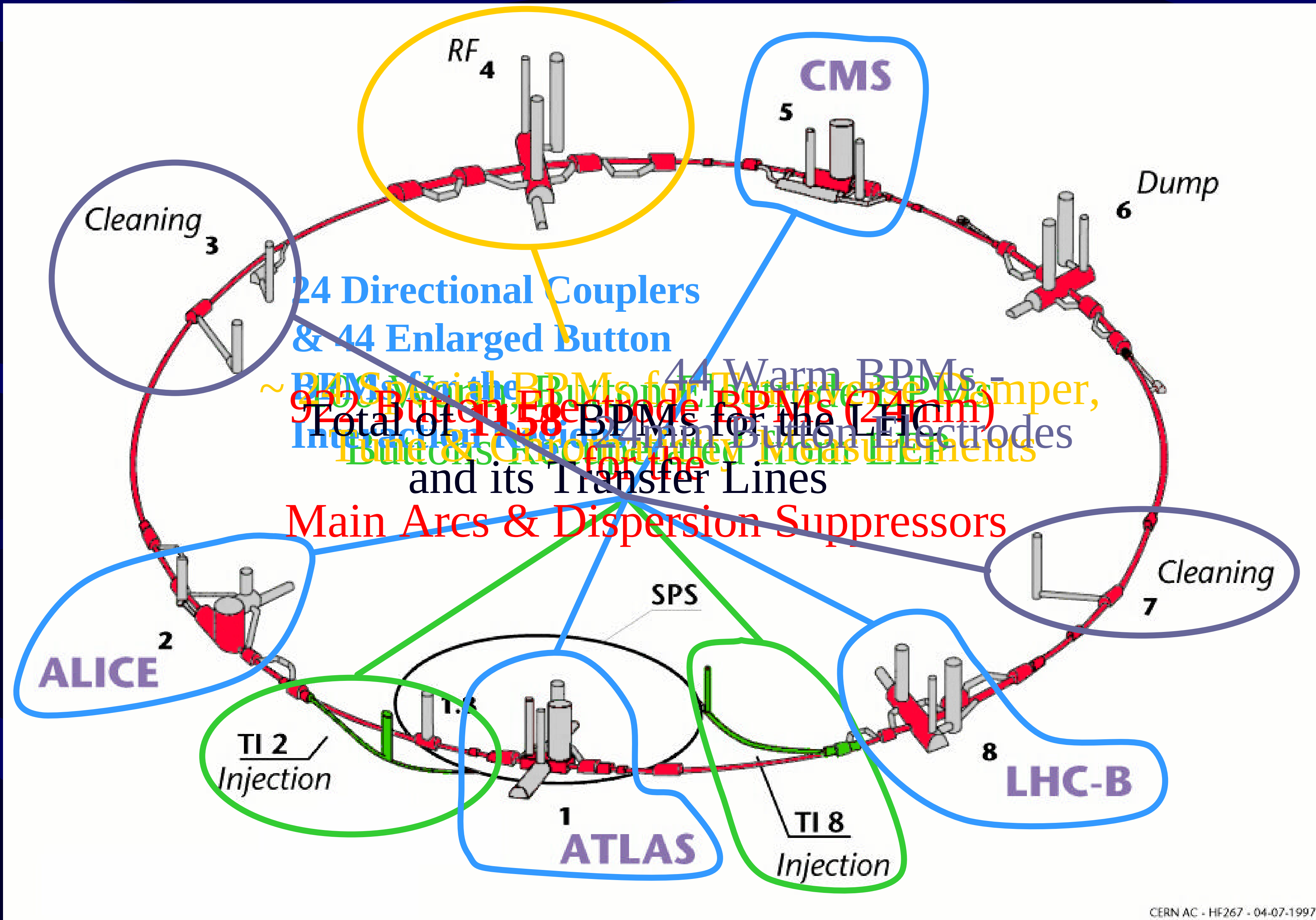
Outline

- LHC Beam Instrumentation
  - → The BPM system
  - → The BLM system
  - → Luminosity monitors
  - → Emittance measurement

Tune, chromaticity & coupling measurement – this workshop

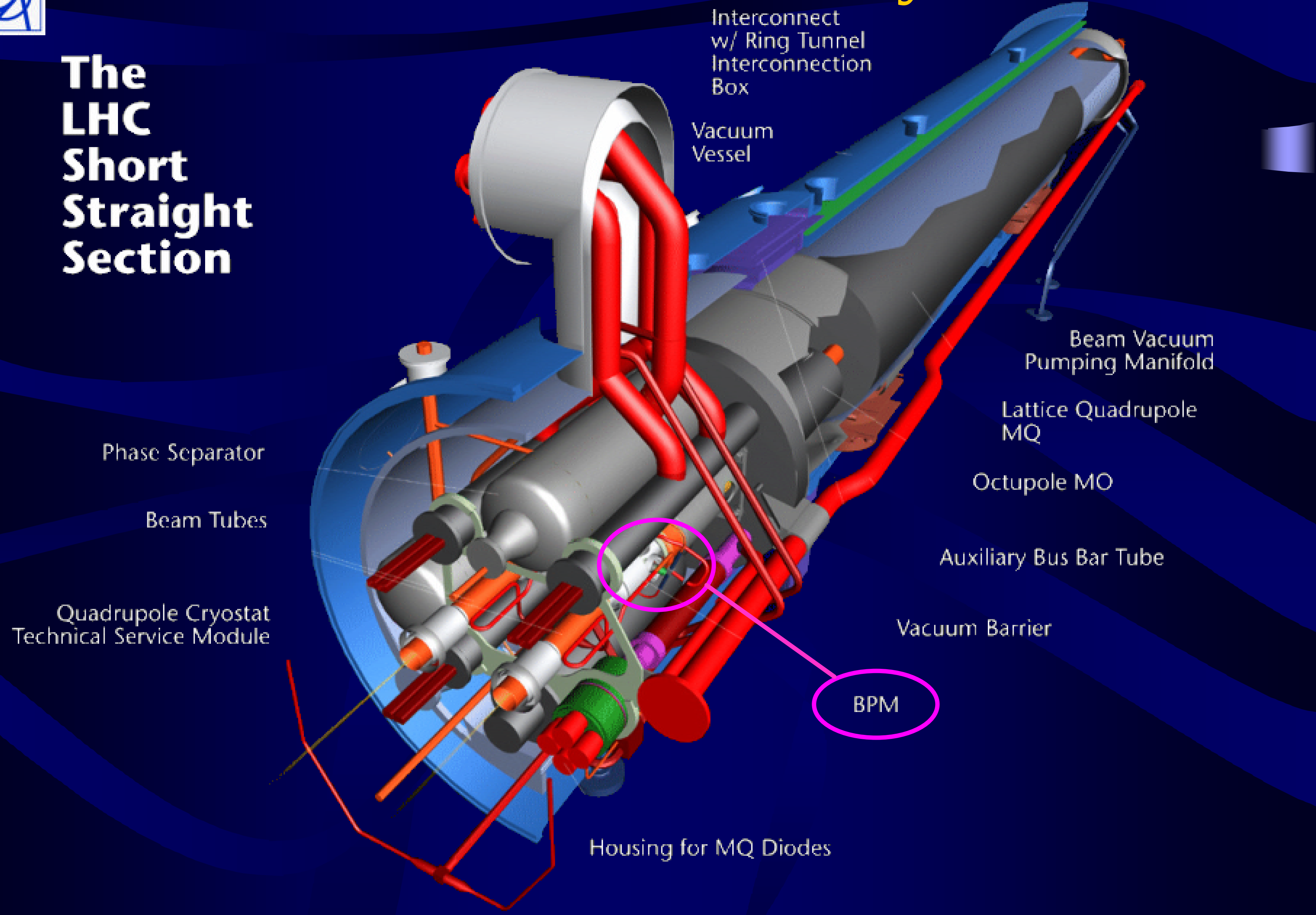
- LHC Commissioning
  - → General commissioning strategy
  - → Commissioning the beam instrumentation

LHC BPM System - General Layout

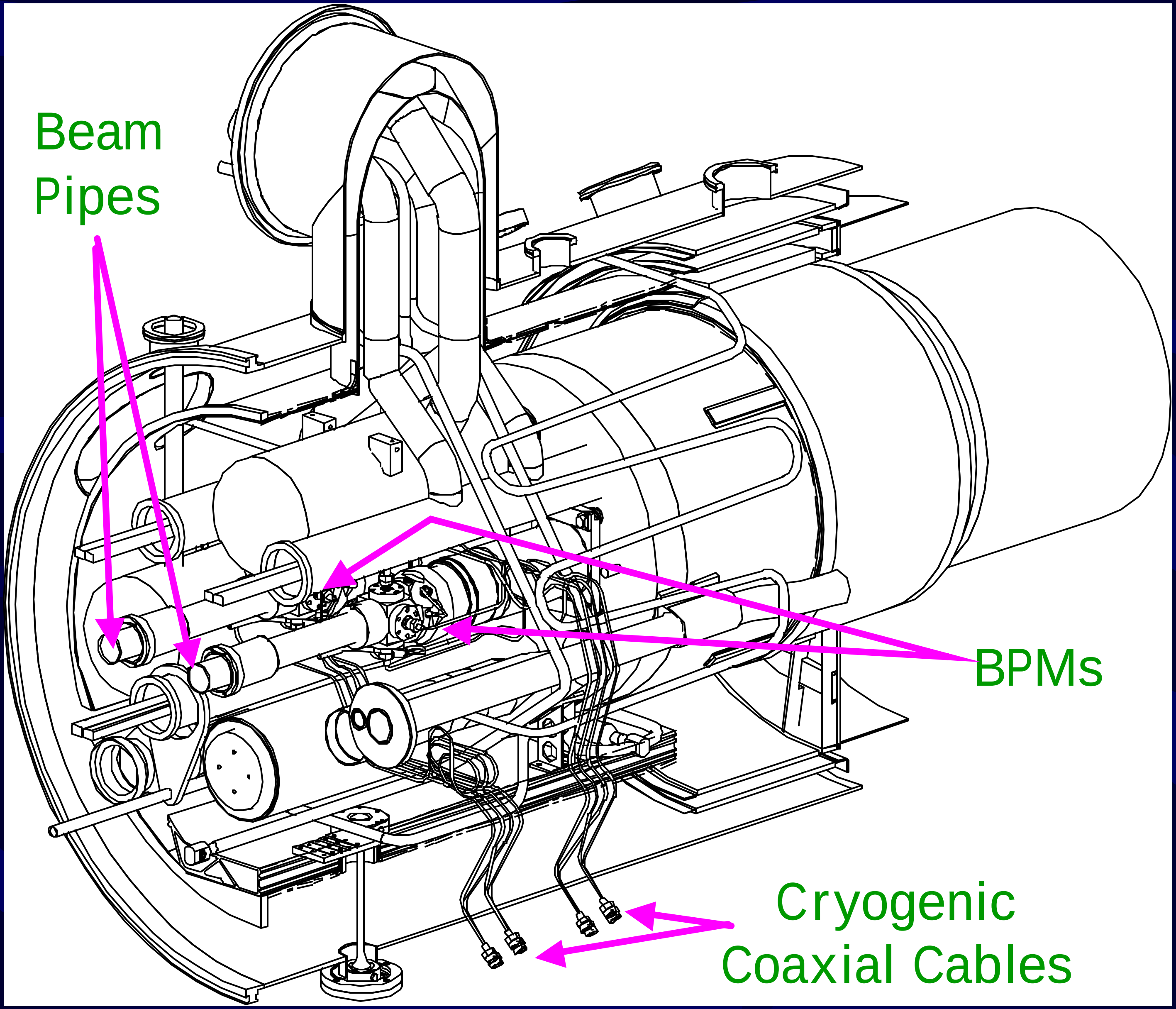


The Arc BPM - SSS Layout

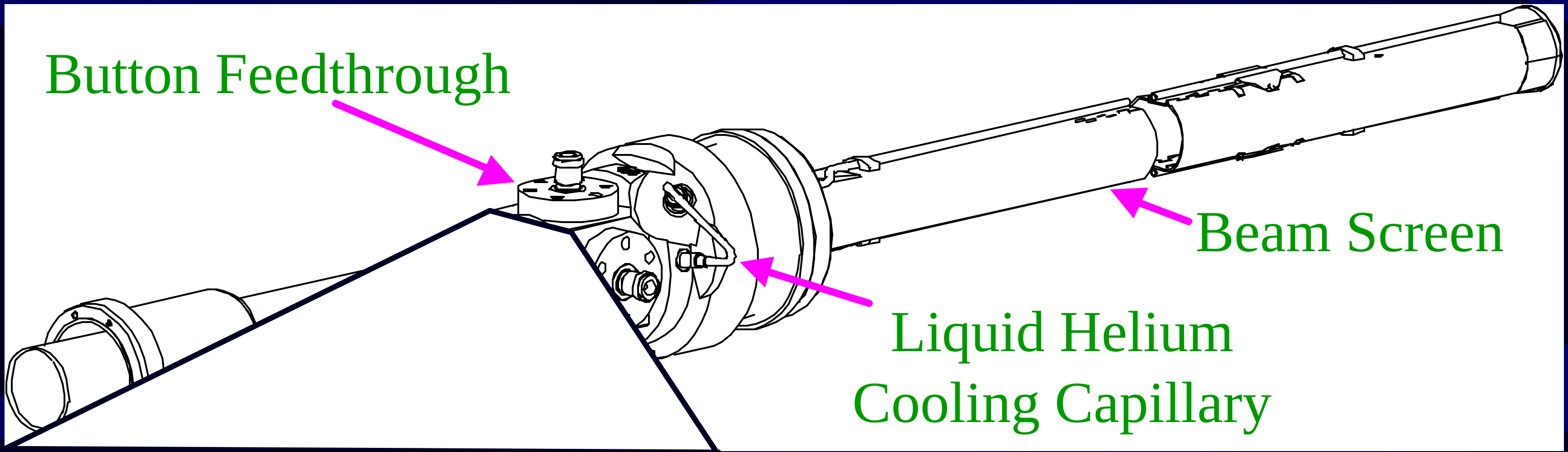
The LHC Short Straight Section

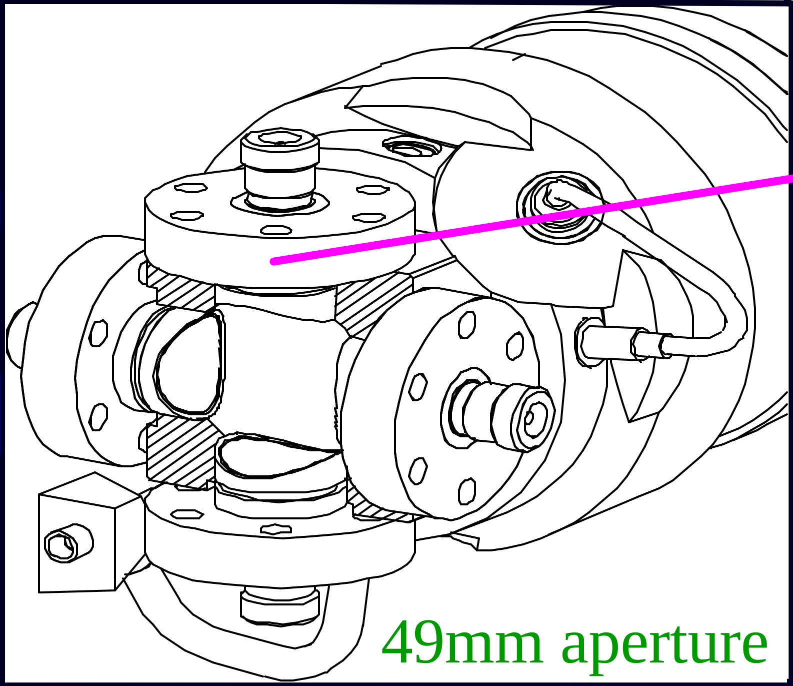


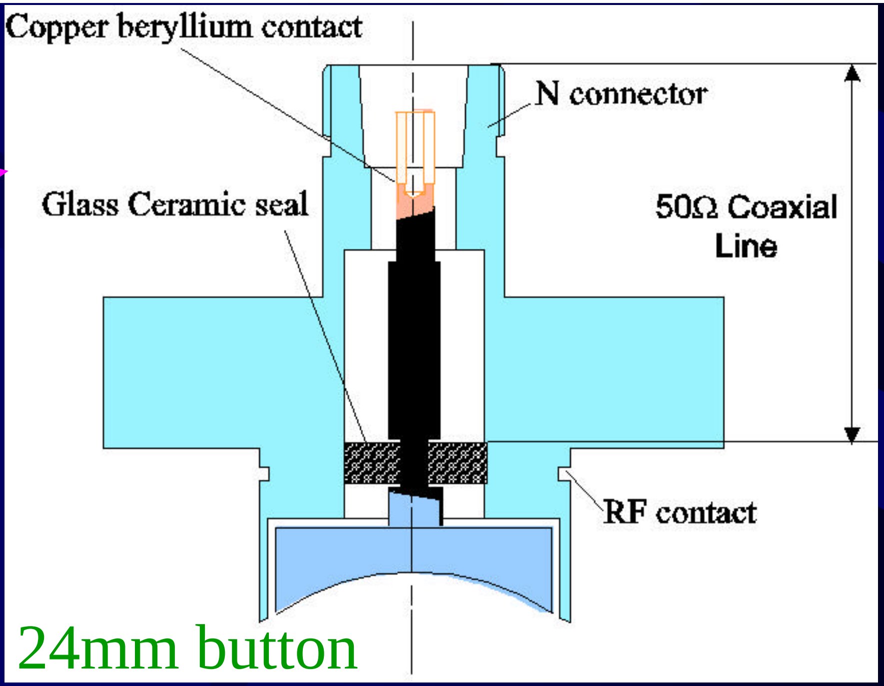
Arc BPM - Detailed Layout



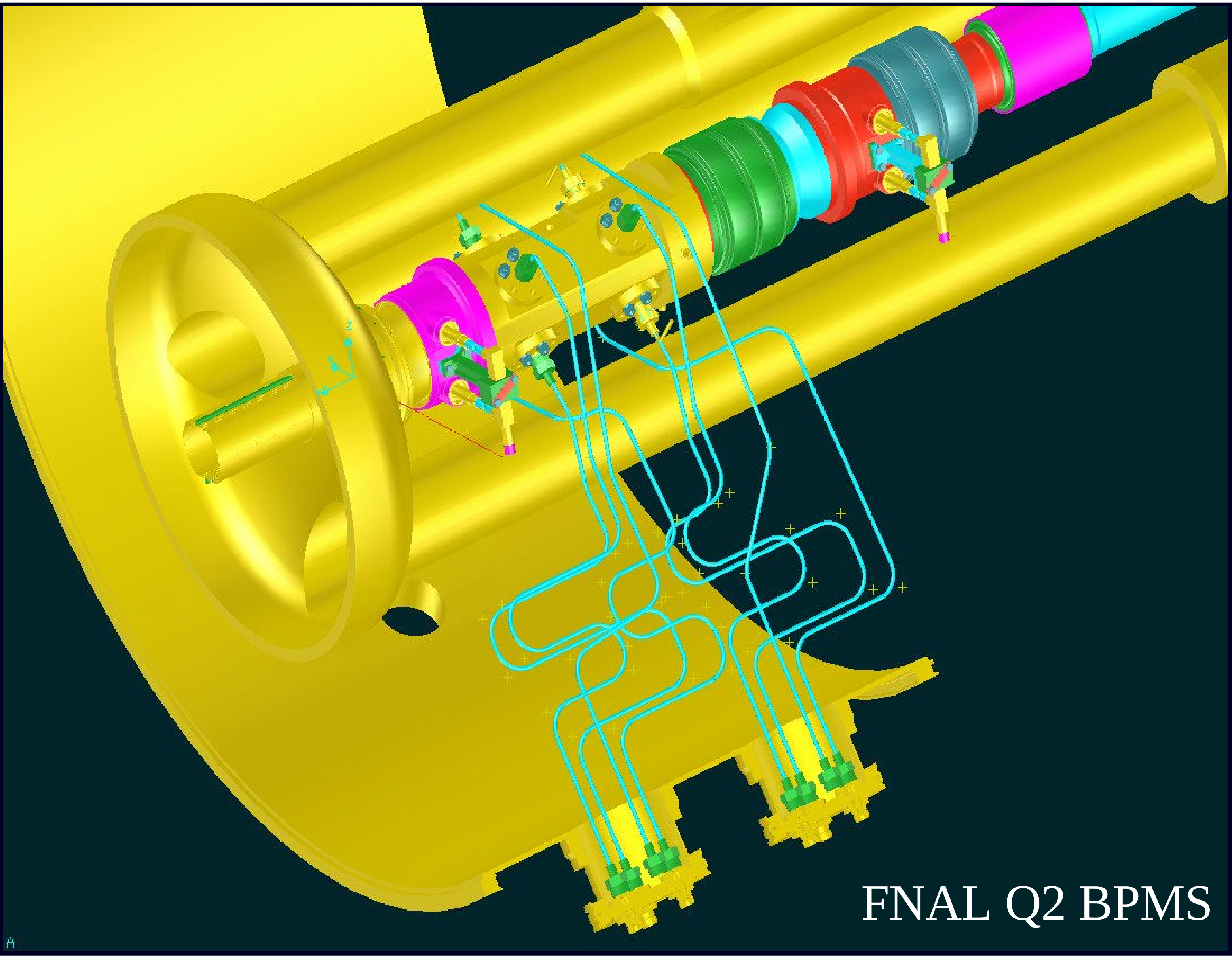
Arc BPM - Button Feedthrough





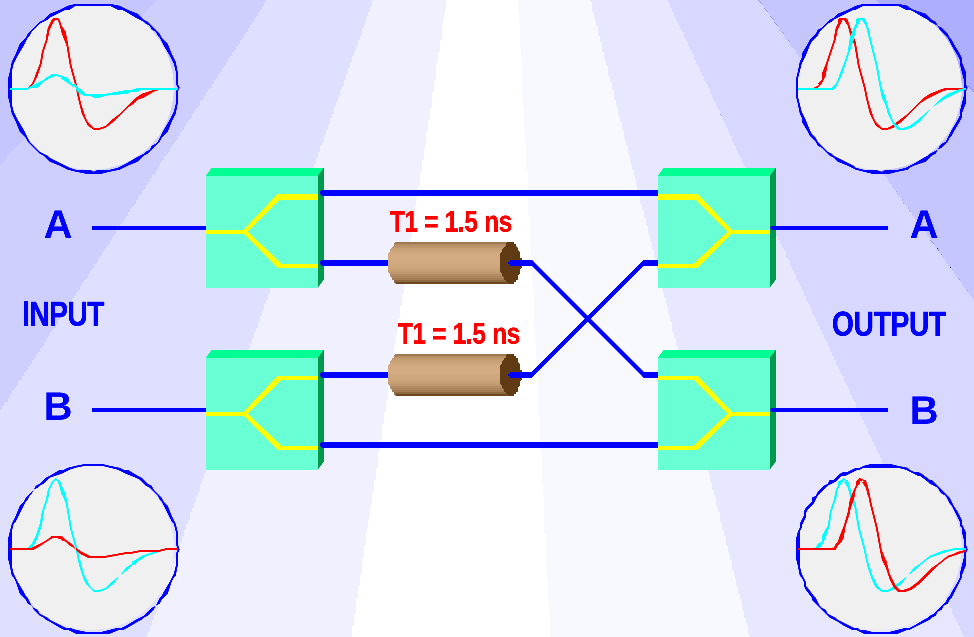


Insertion Region Directional Couplers

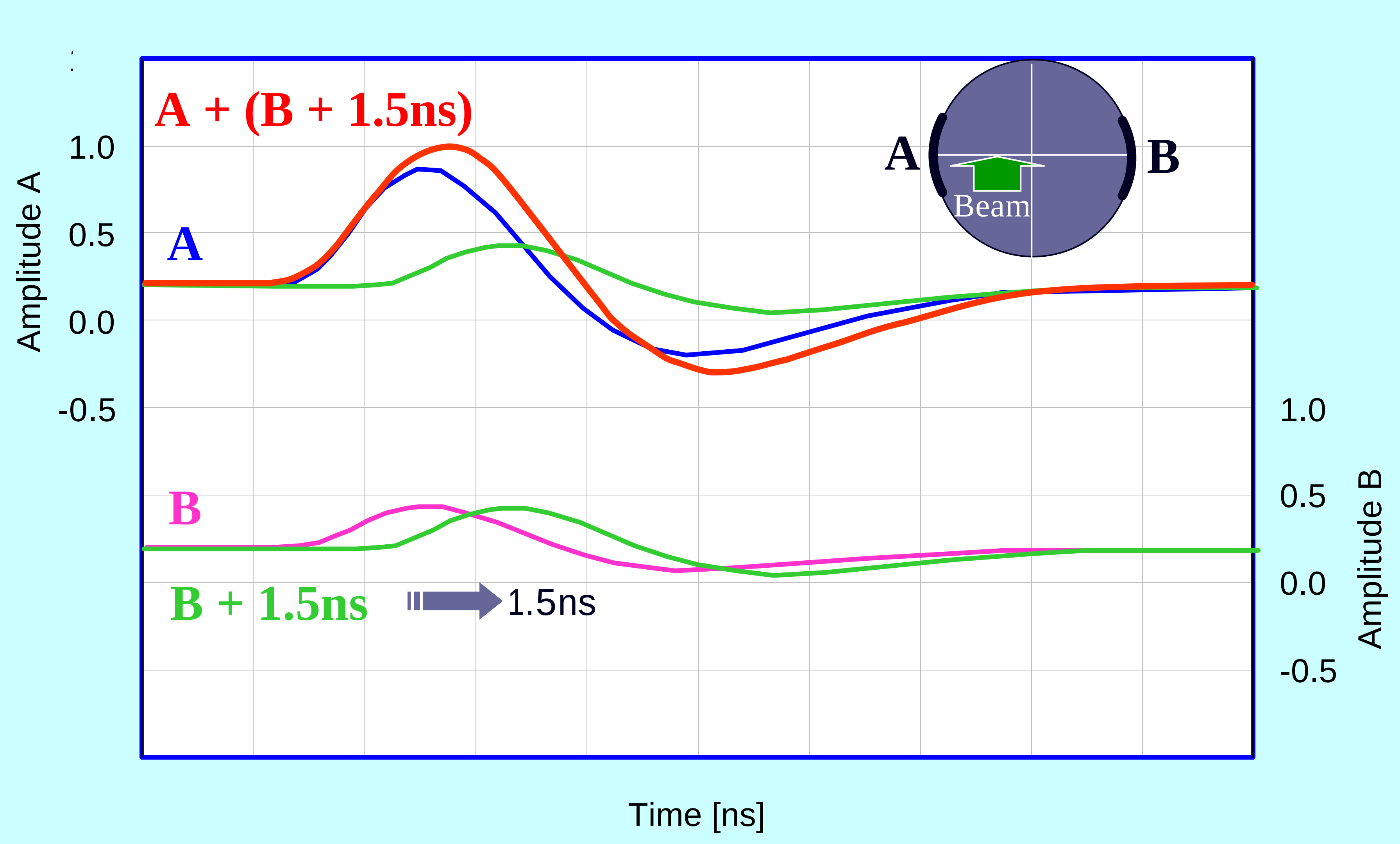


The Front-End Electronics

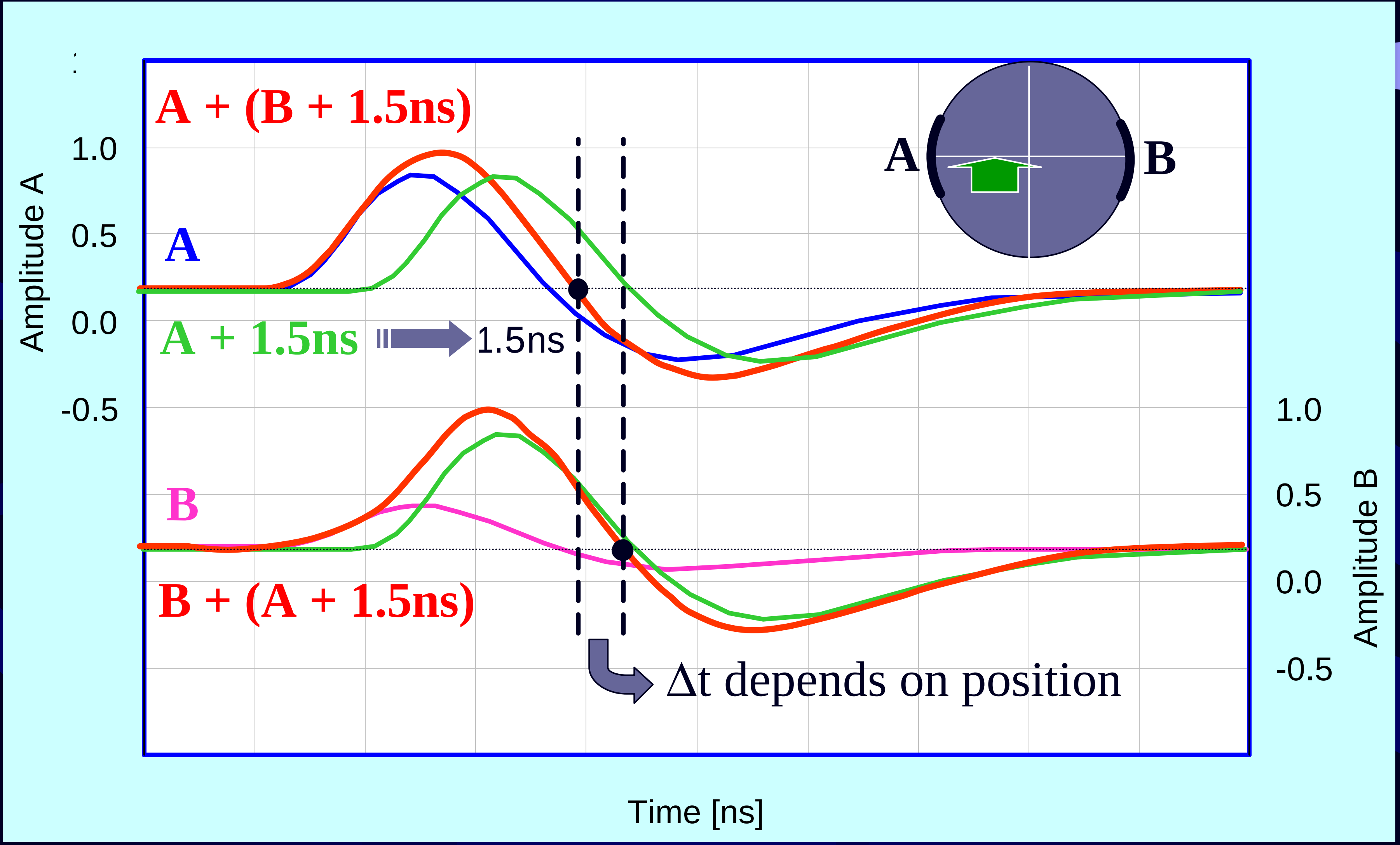
WIDE BAND TIME NORMALISER PRINCIPLE (WBTN)



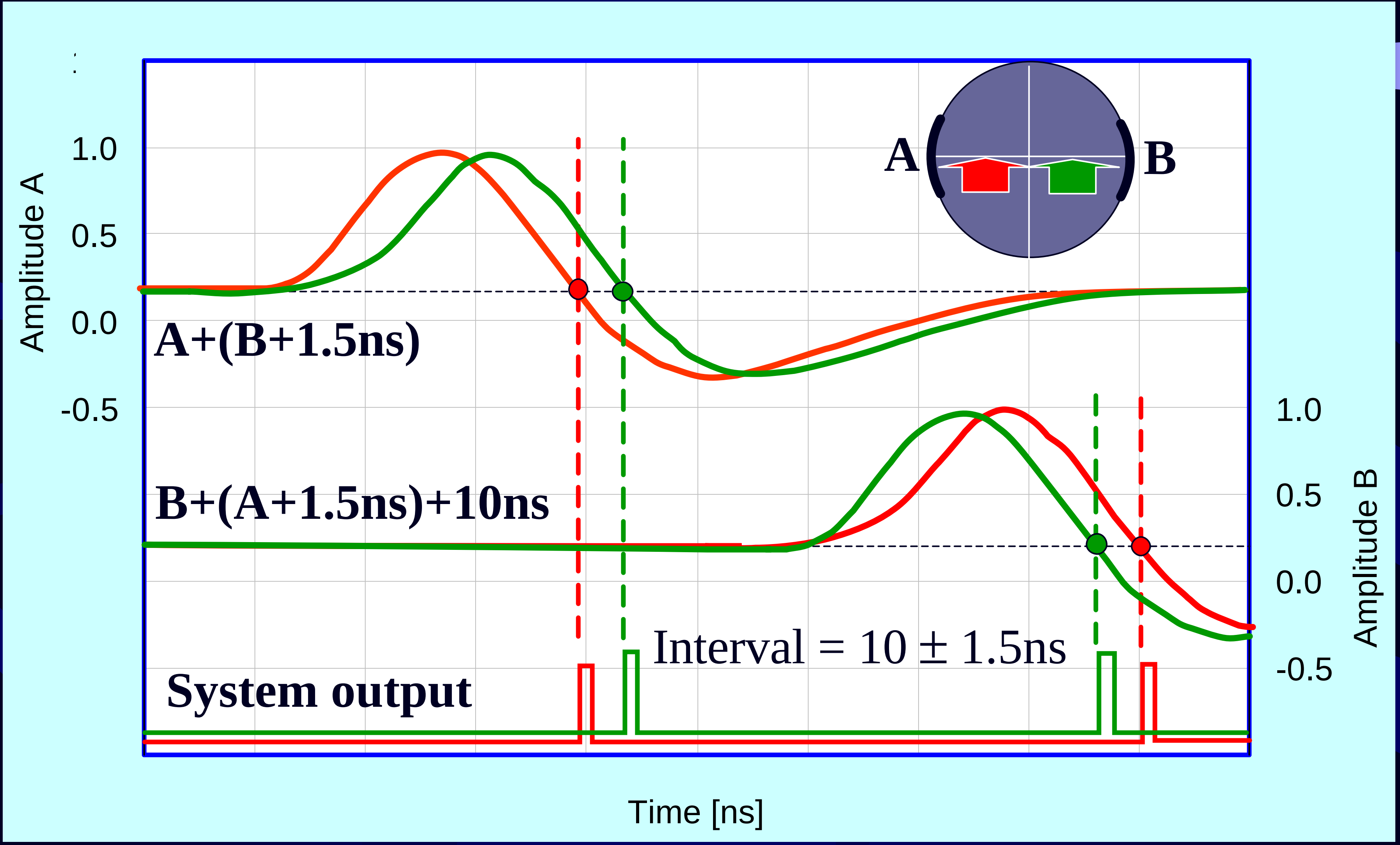
The Wide Band Time Normaliser



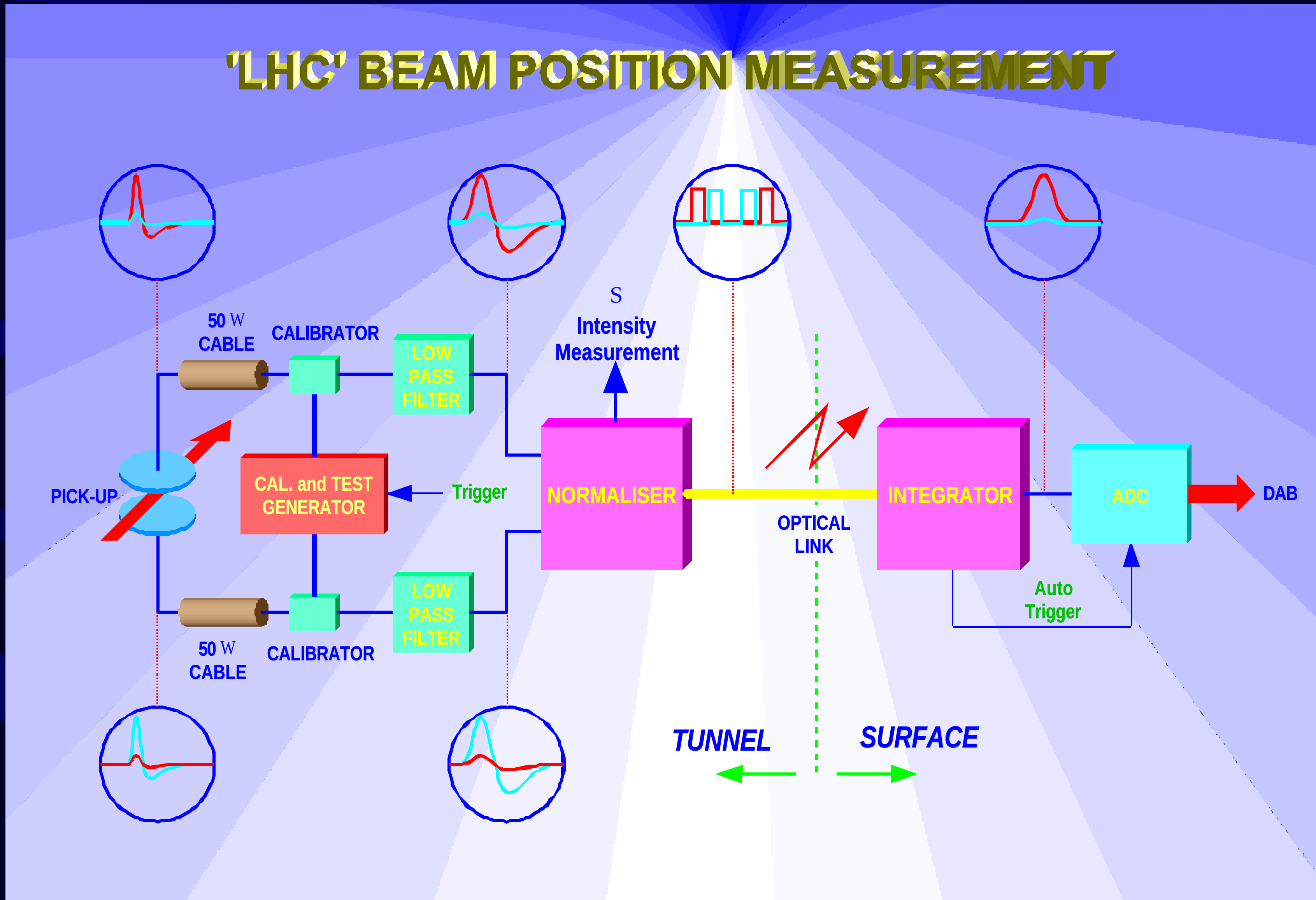
The Wide Band Time Normaliser



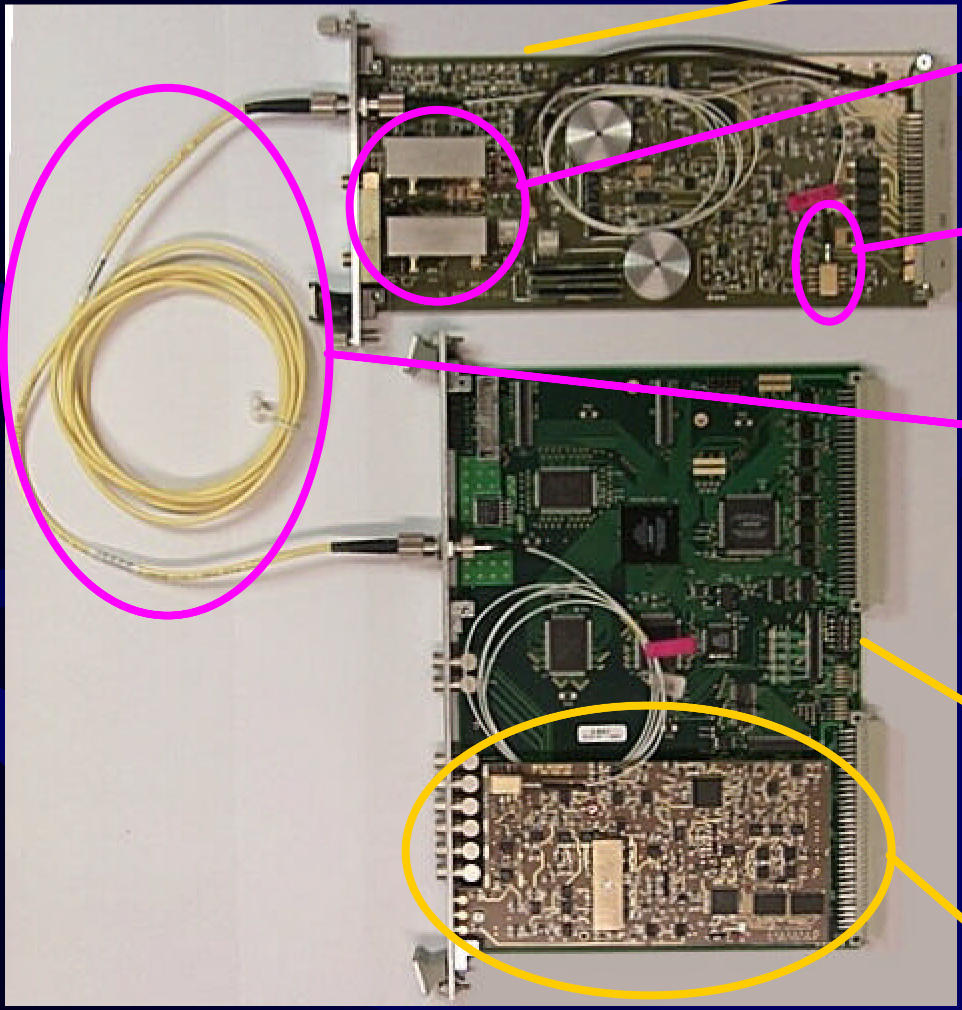
The Wide Band Time Normaliser



The Wide Band Time Normaliser



The LHC BPM Acquisition System



Very Front-End WBTN Card

70MHz Low Pass Filters
Supplied by TRIUMF (Canada)

1310nm Diode Laser Transmitter

Tunnel

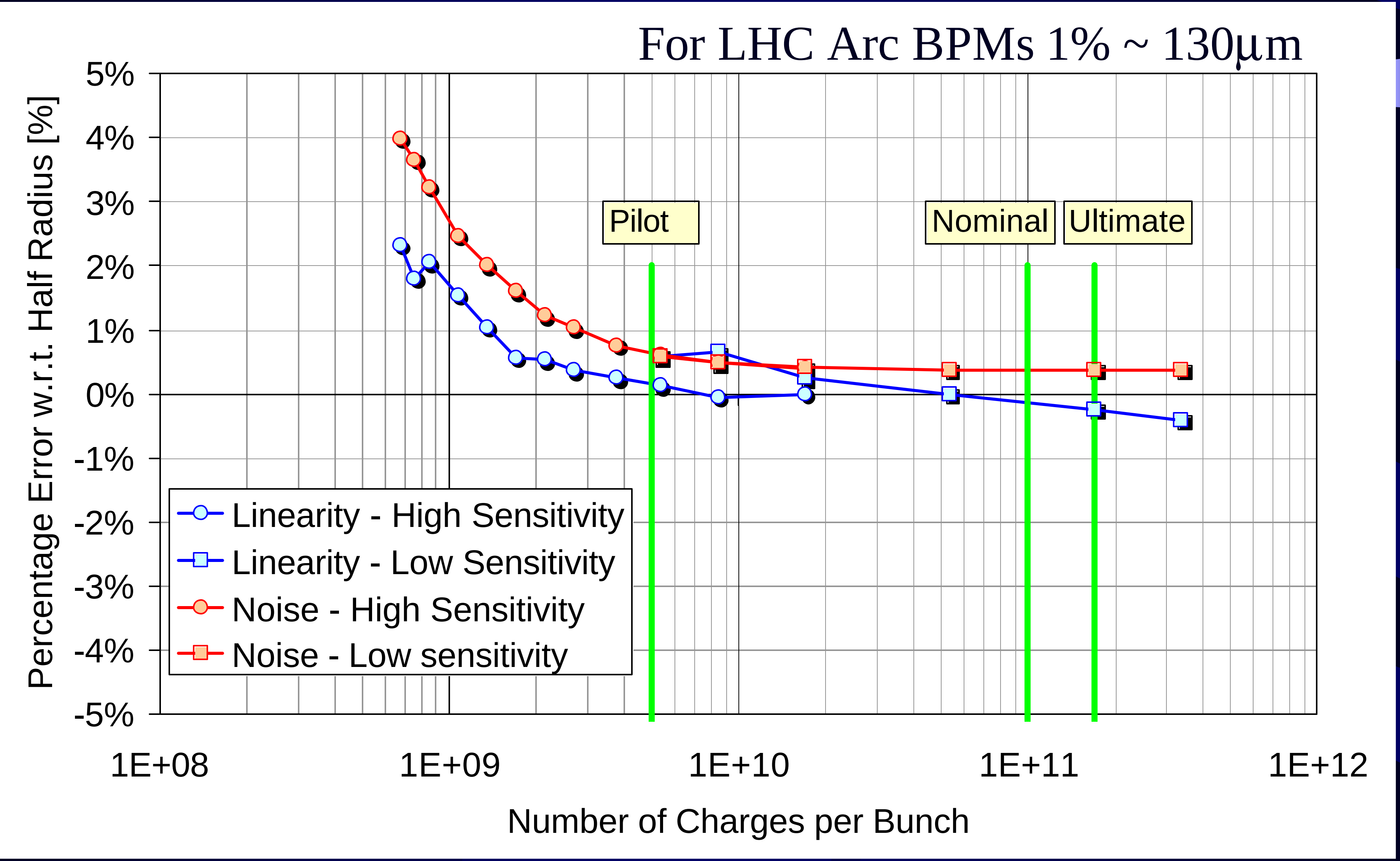
Single-Mode Fibre-Optic Link

Surface

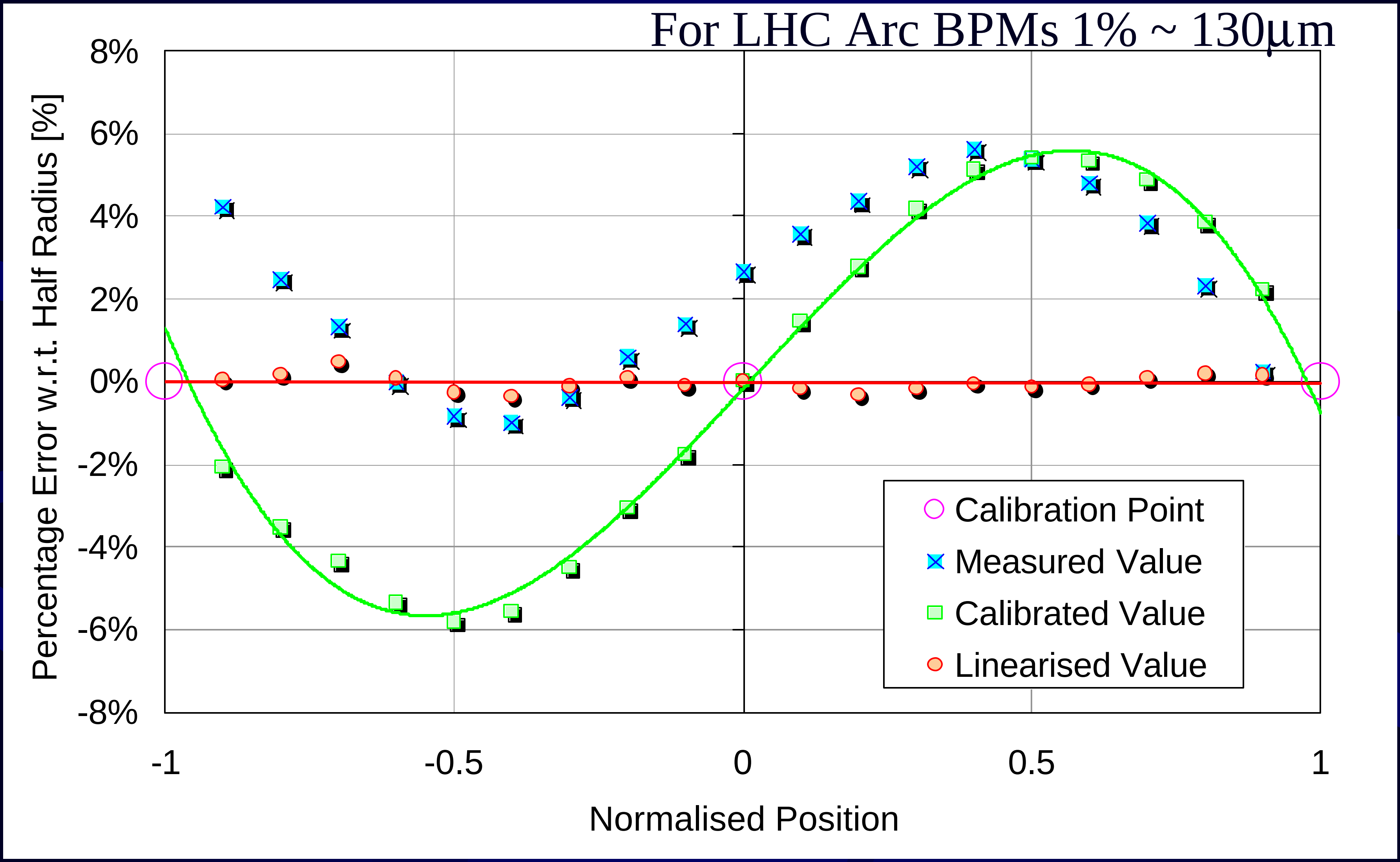
VME based
Digital Acquisition Board
TRIUMF (Canada)

WBTN Mezzanine Card
(10bit digitisation at 40MHz)

WBTN - Linearity v Intensity

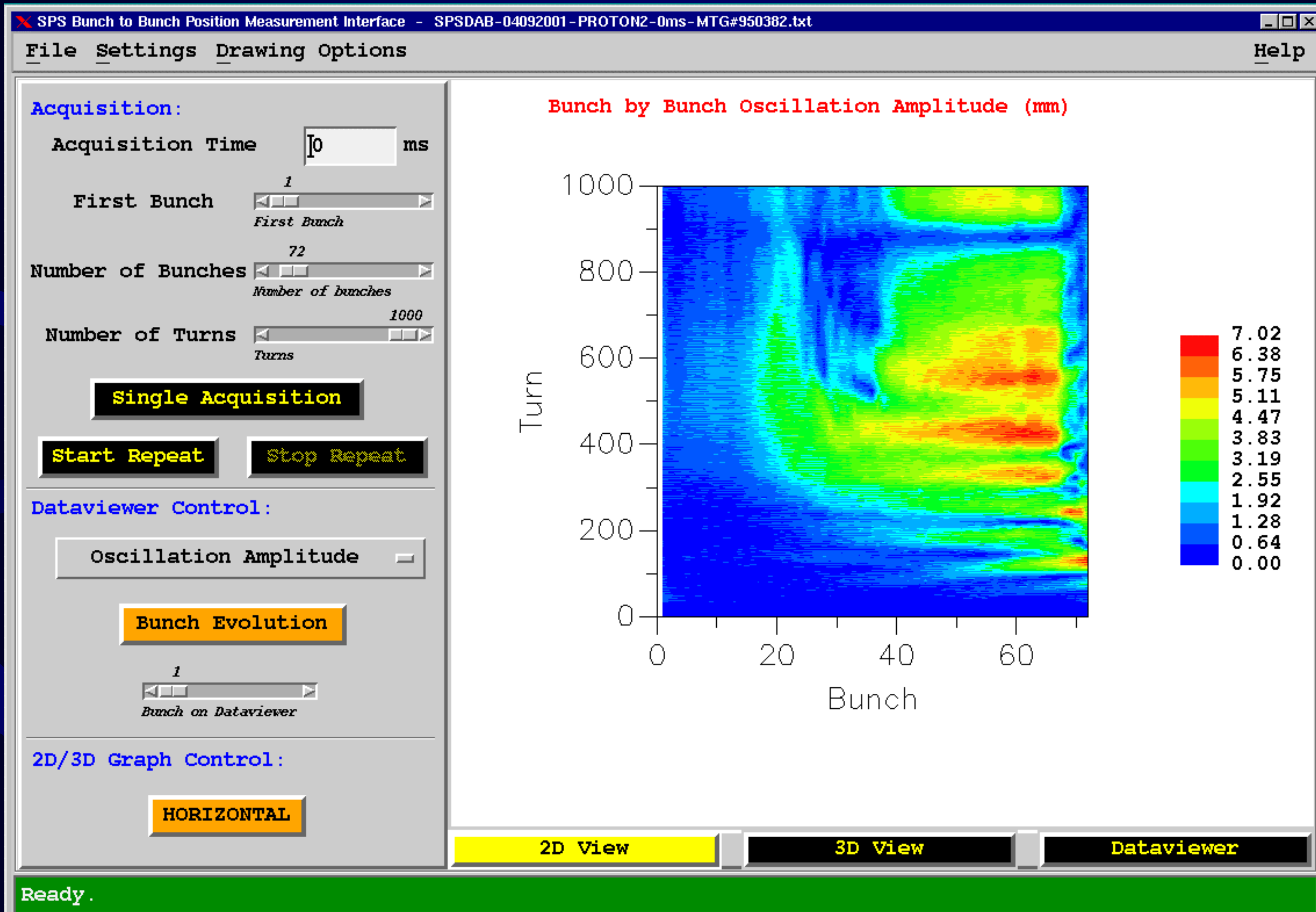


WBTN - Linearity v Position



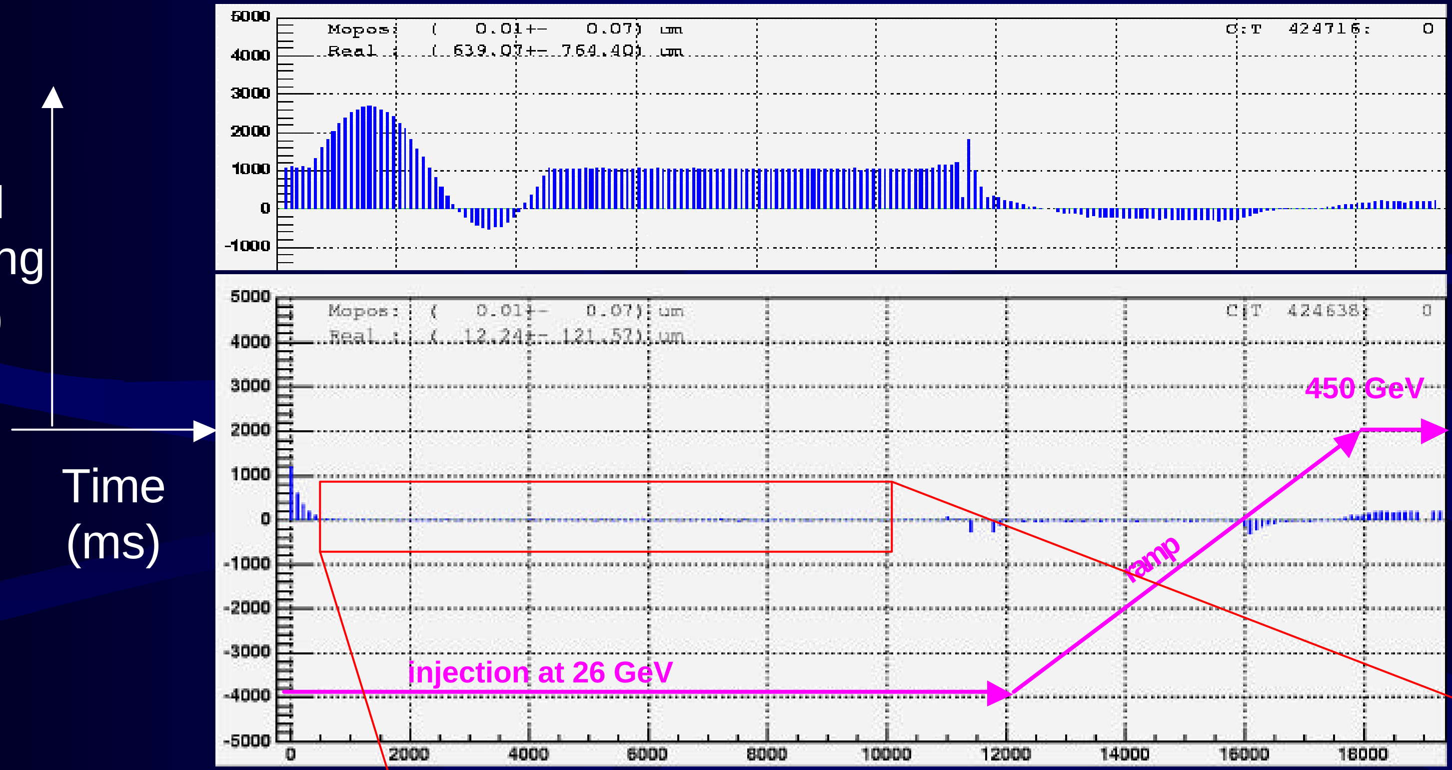
Bunch-by-bunch Results in the CERN-SPS

System extensively used in SPS for electron cloud & instability studies.



Orbit feedback results from the CERN-SPS

BPM Reading (µm)



Time (ms)

feedback off

feedback on

Position distribution
@ 100 Hz
$\sigma = 8.5\ \mu m$

The LHC Beam Loss System

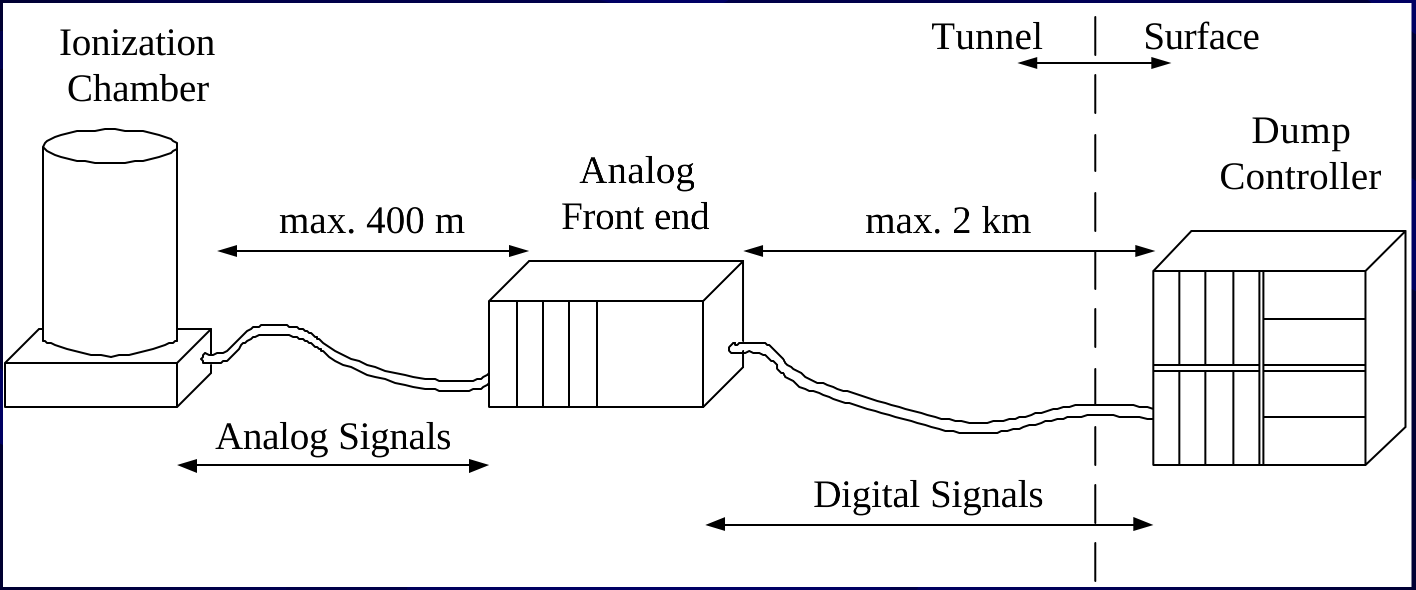
Role of the BLM system:

1. Protect the LHC from damage
2. Dump the beam to avoid magnet quenches
3. Diagnostic tool to improve the performance of the LHC

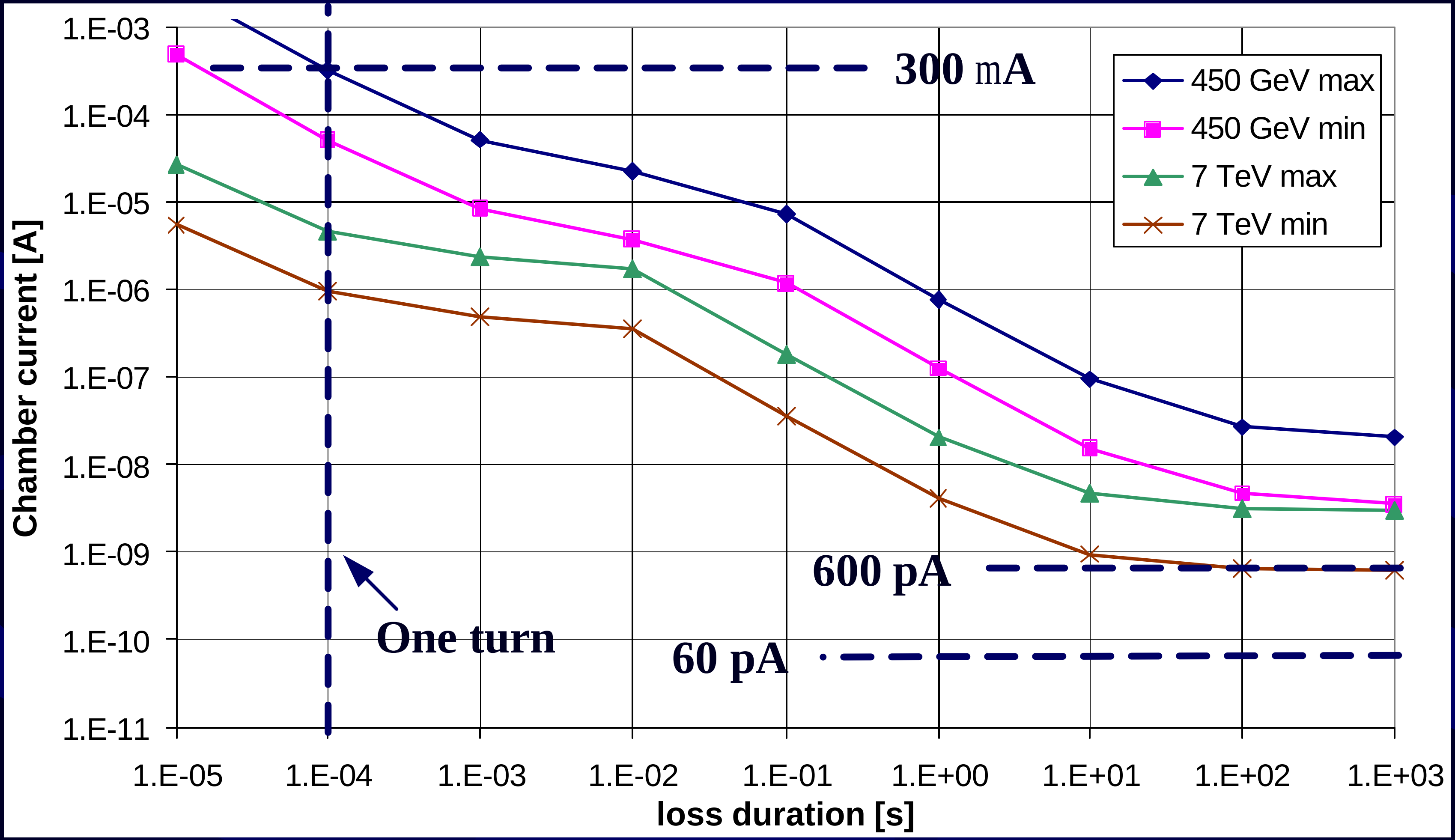
- Acquisition requirements:
  - → Calculation of quench level equivalent chamber signal
    - – Electric currents from 600 pA to 300 µA
  - → A dump should be requested at 50% of the quench level
    - – i.e. from 300 pA to 150 µA
  - → Extend dynamic range for sufficient sensitivity at low losses
    - – Measuring current from 60 pA to 300 µA
  - → Arc BLM acquisition rate not faster than one turn (89 µs)
    - – Fastest total loss is ~ 6 turns & will be detected by special BLMs.

Structure of the BLM Readout Chain

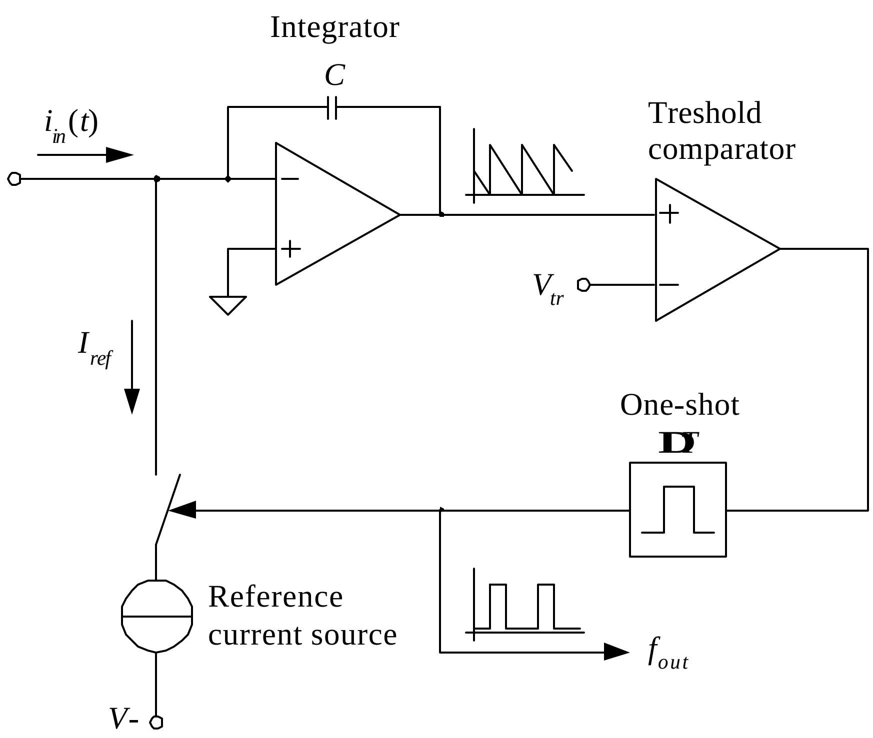
- Ionisation Chamber
  - → transforms particle losses into an electric current
  - → 6 per quadrupole (3 for each LHC ring) ⇒ ~3000 monitors
- Analogue Front-End
  - → measures current and transmits data from Tunnel ⇒ Surface
- Dump Controller
  - → processes data and interfaces to the beam interlock system

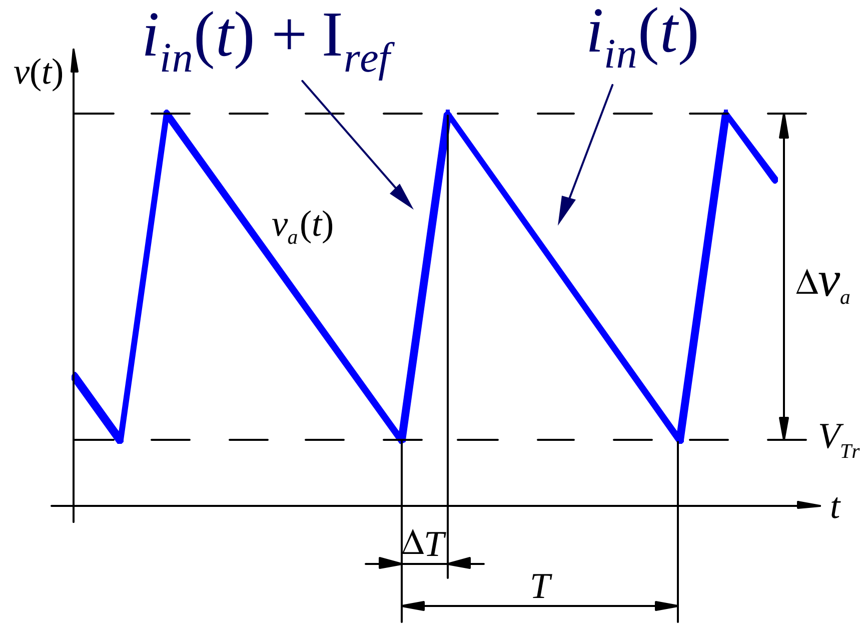


Quench Level Equivalent Chamber Current



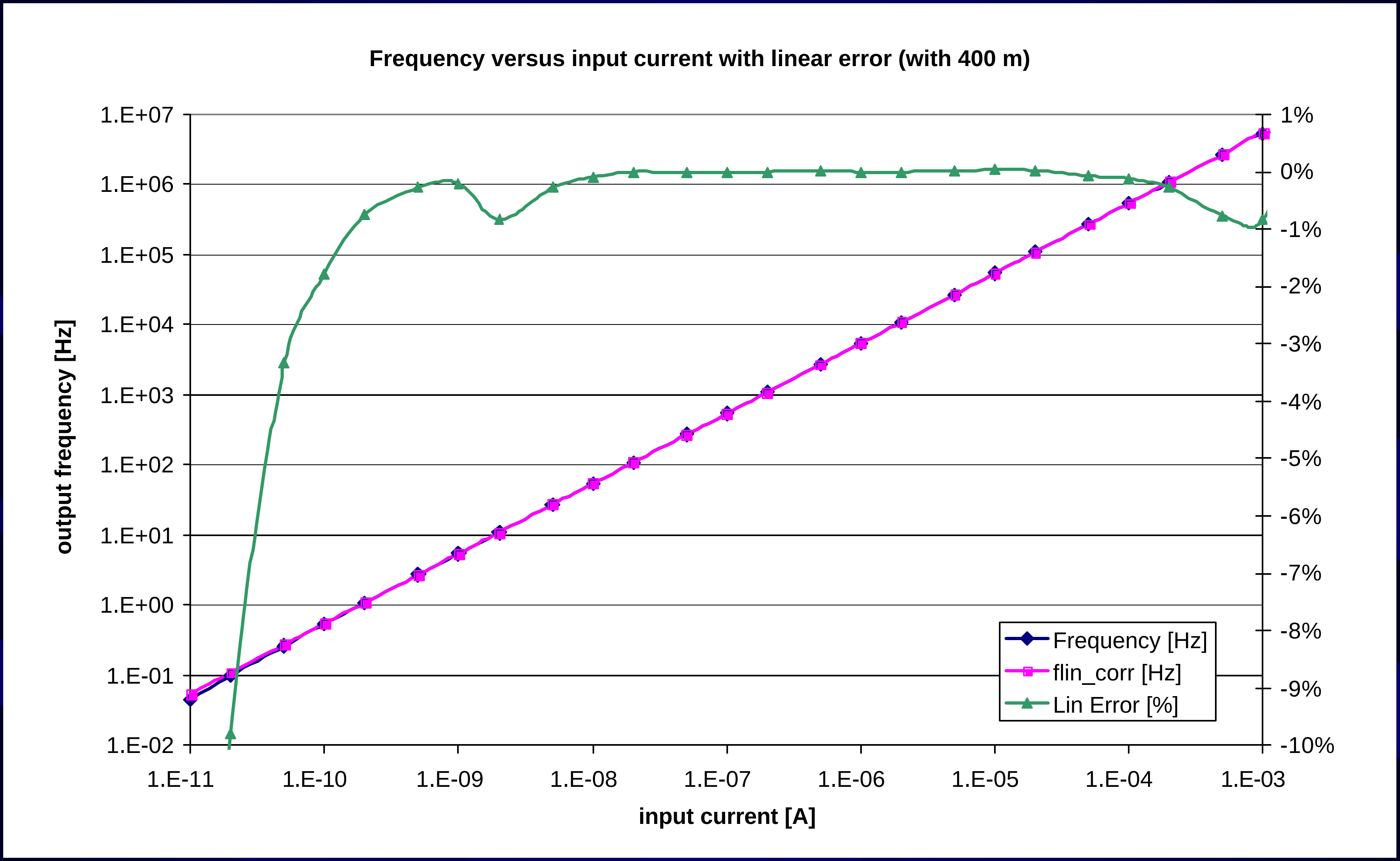
Charge-Balanced Converter





$$f = \frac{\overline{i_{in}}}{I_{ref}\Delta T}$$

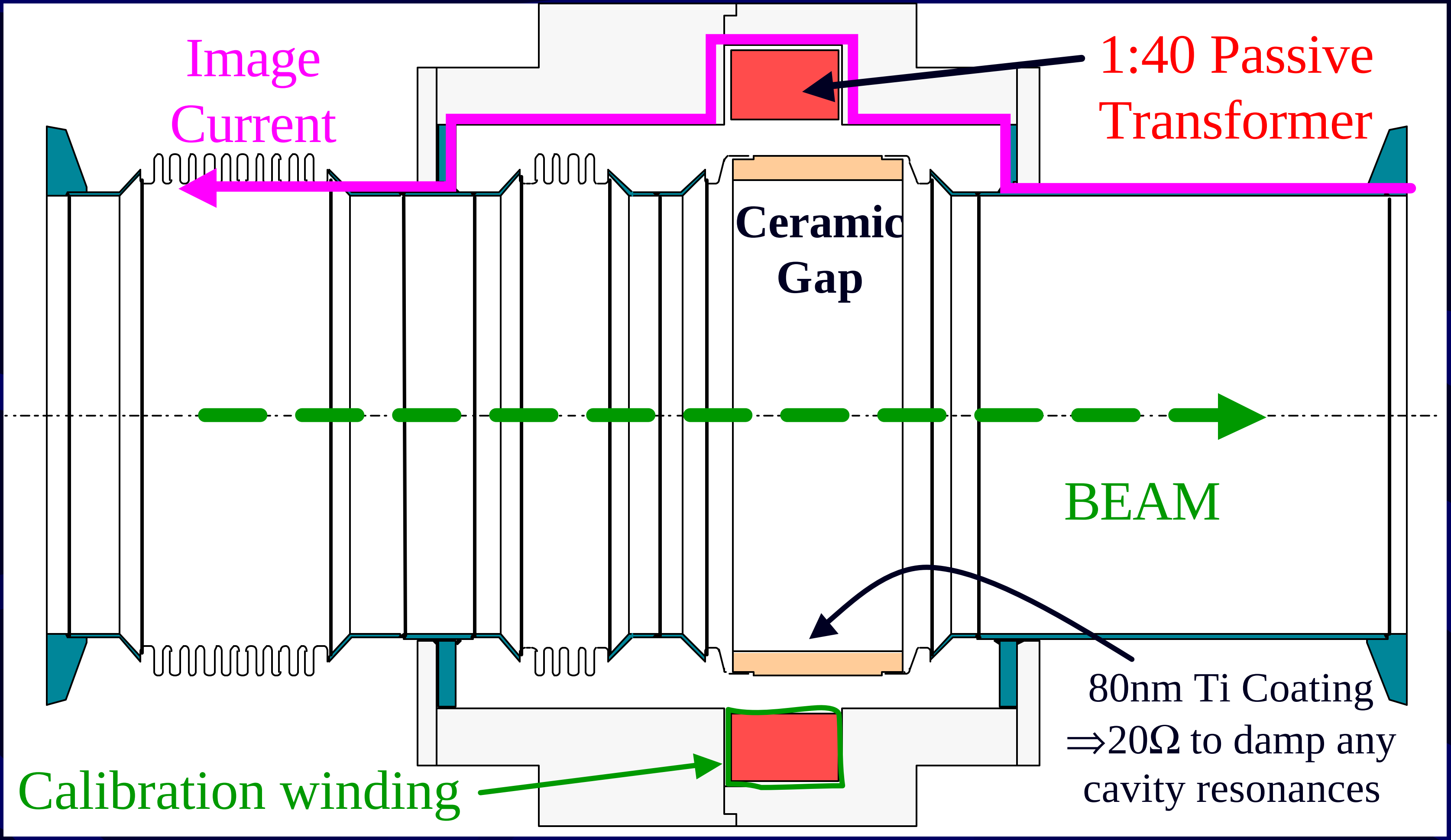
Current-Frequency Characteristics



Fast Beam Current Transformer

- Installed in the SPS and LHC transfer lines
- LHC fast BCT will be a scaled version
- Capable of 40MHz bunch by bunch measurement
- Dynamic range to cover 5×10^9 to 1.7×10^{11} cpb

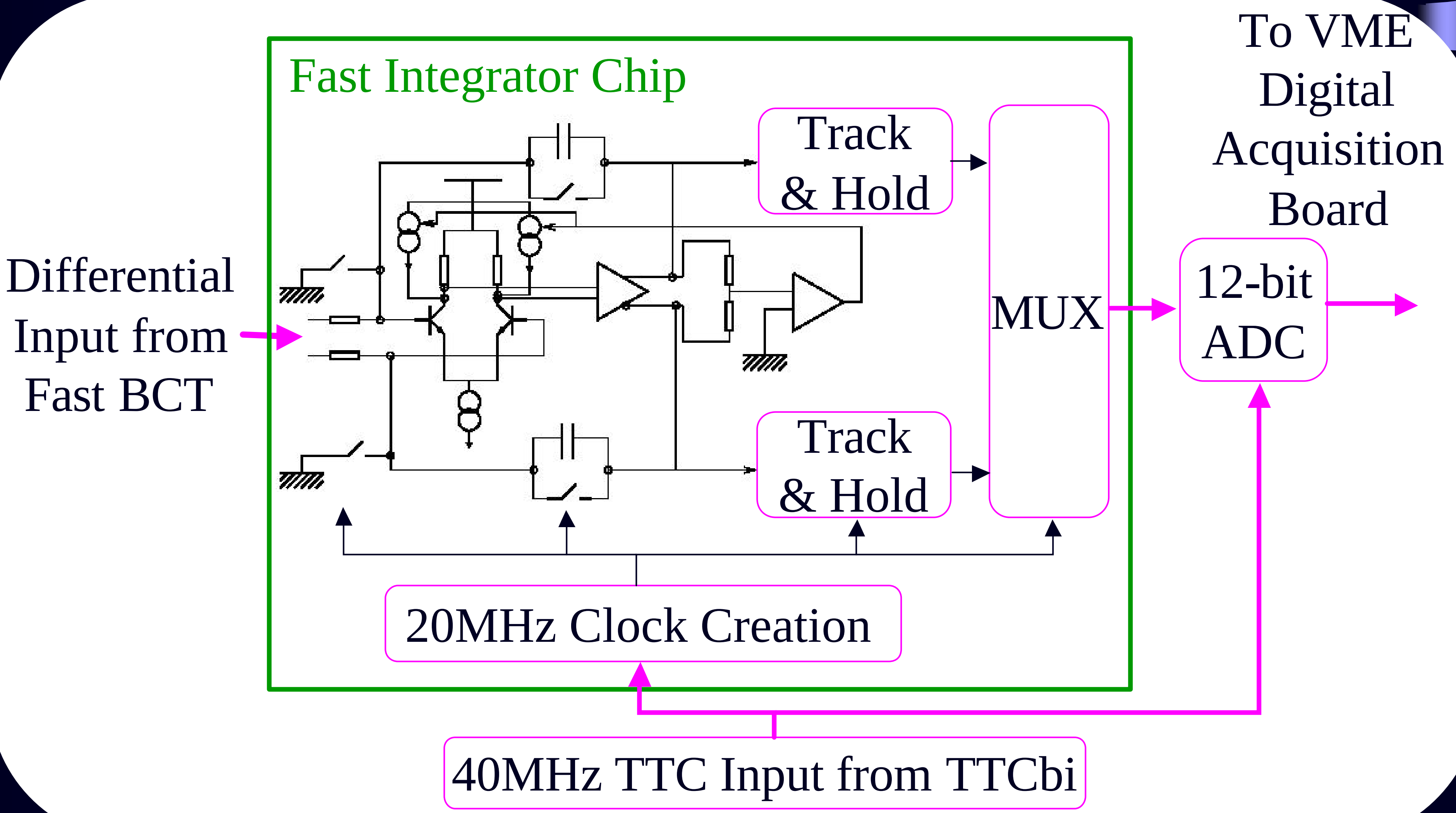
Fast Beam Current Transformer



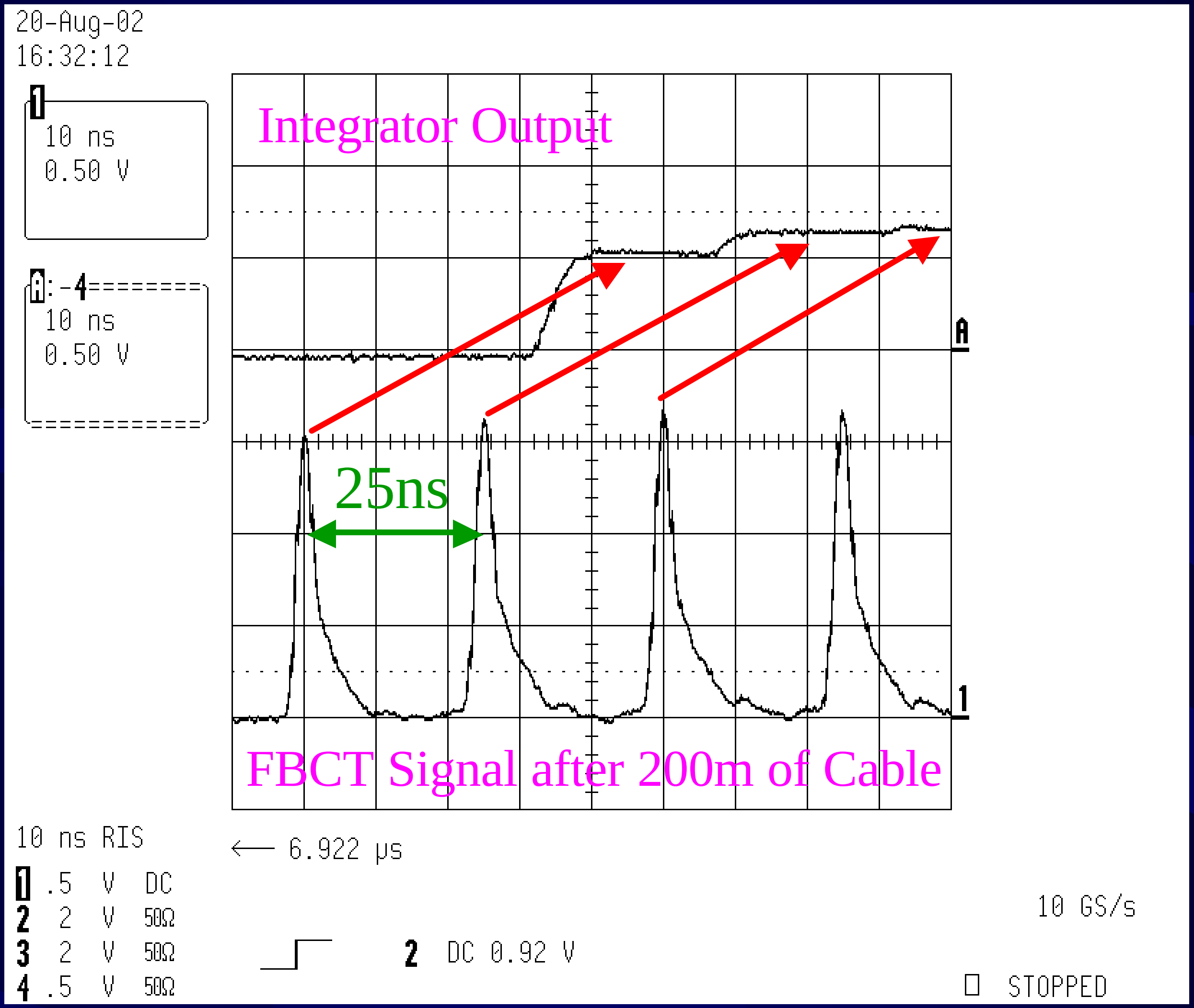
- 500MHz Bandwidth
- Low droop (< 0.2%/µs)

Acquisition Electronics

ASIC developed by the Lab. de Physique Corpusculaire, Clermont-Ferrand, France
Used in the LHCb Preshower Detector.

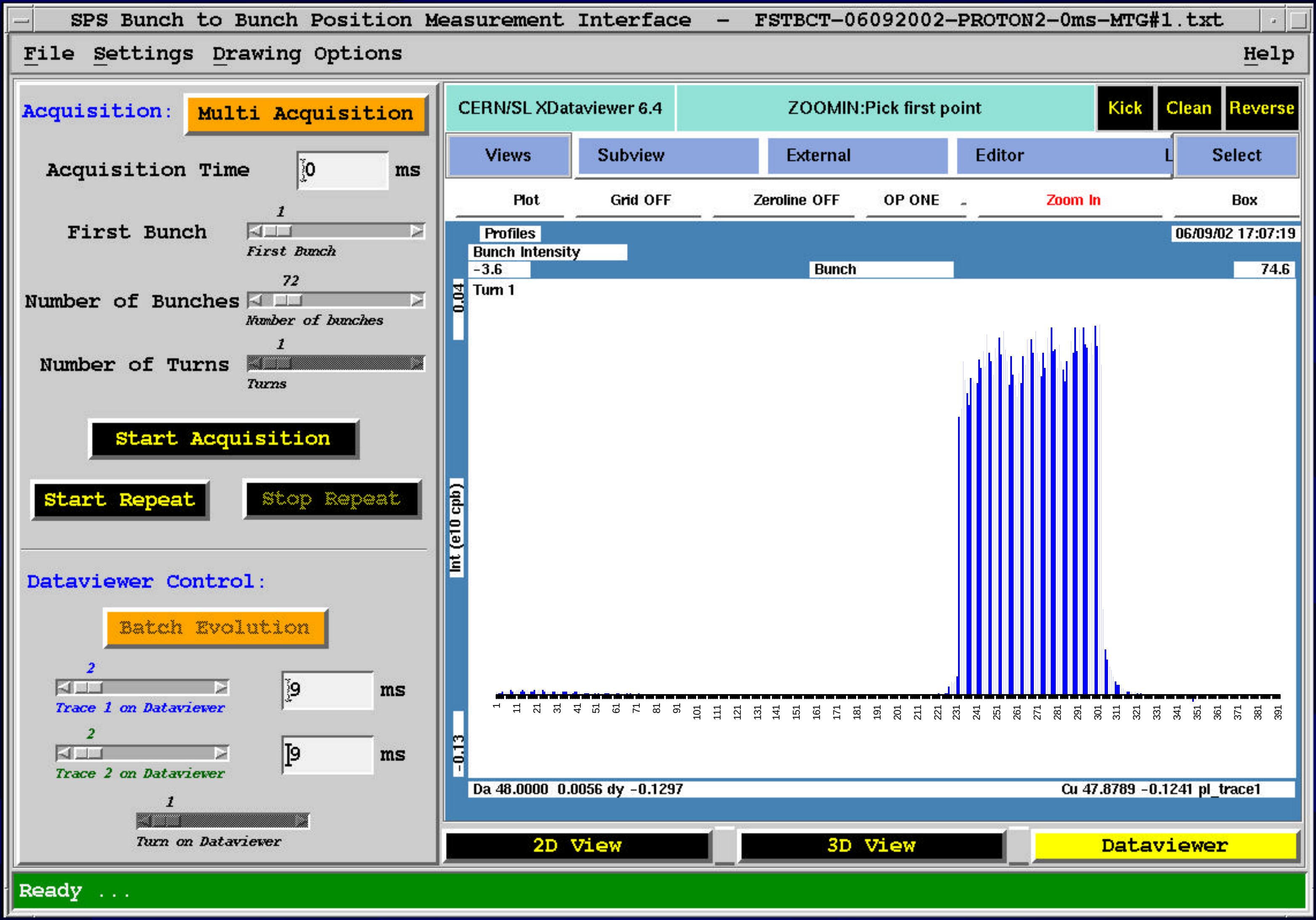


Acquisition Electronics



Data taken on LHC type beams at the CERN-SPS (2002)

Results from the CERN-SPS (2002)



Bad RF Capture of a single SPS LHC Batch (72 bunches)

LHC Luminosity Measurement

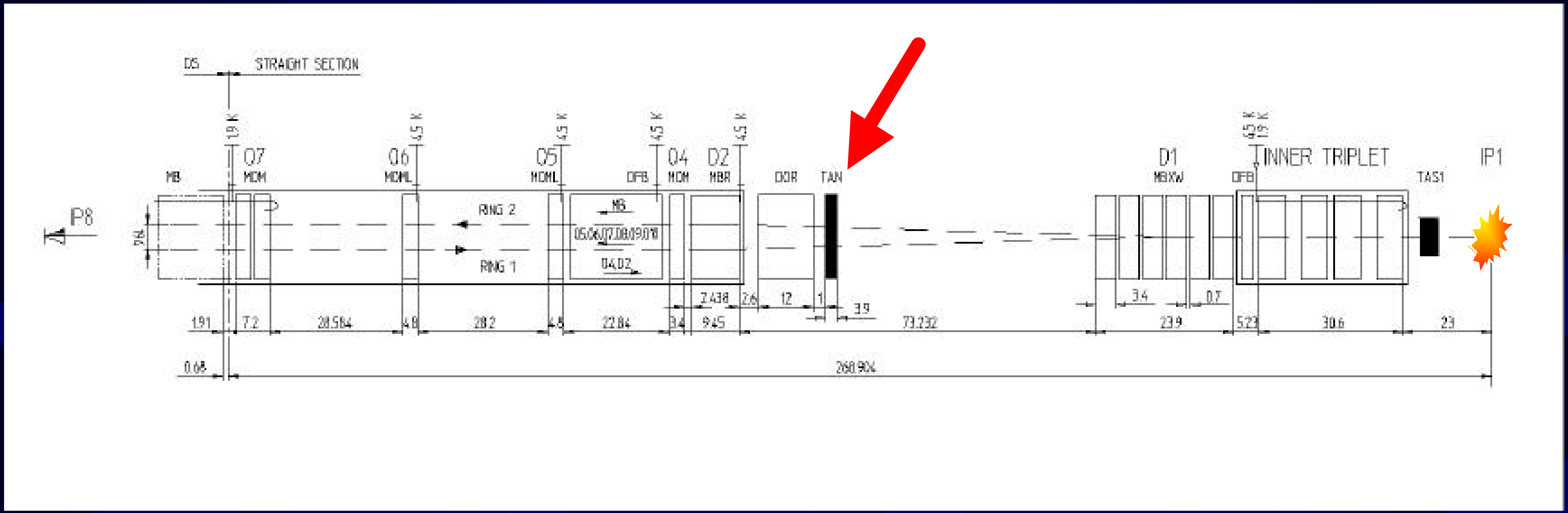
Requirements:

- Capable of 40MHz acquisition
- Has to withstand high radiation dose: ~10^8 Gy/year
  - → estimated 10^{18} Neutrons/cm^2 over its lifetime (20yrs LHC operation)
  - → estimated 10^{16} Protons/cm^2 over its lifetime (20yrs LHC operation)
- No maintenance

Candidates:

- Ionisation Chambers
  - → developed by LBL
    - Good radiation hardness
    - Difficult to get working at 40MHz
- CdTe detectors
  - → developed by CERN in collaboration with LETI (Grenoble)
    - Fulfills 40MHz requirement
    - Not yet proven for the highest levels of radiation

Nominal locations of the front quadrupole (TAS) and neutral (TAN) absorbers



- The TAS absorbs forward collision products that have escaped the beam tube in front of Q1 (mostly charged pions and photons)

- The TAN absorbs forward neutral collision products (mostly neutrons and photons) and is placed in front of the outer beam separation dipole D2

The LHC Emittance Budget

- From the particle source to “colliding beams” in the LHC the emittance may grow by 30% for nominal machine performance

→ an overall increase of only 7% in the LHC itself

→ beam instrumentation & diagnostics

- Given a 2% emittance “Budget” from injection to collisions

→ we have to measure emittance to a precision of a few (1..2) %

- Precise profile measurements
- On-line β measurements

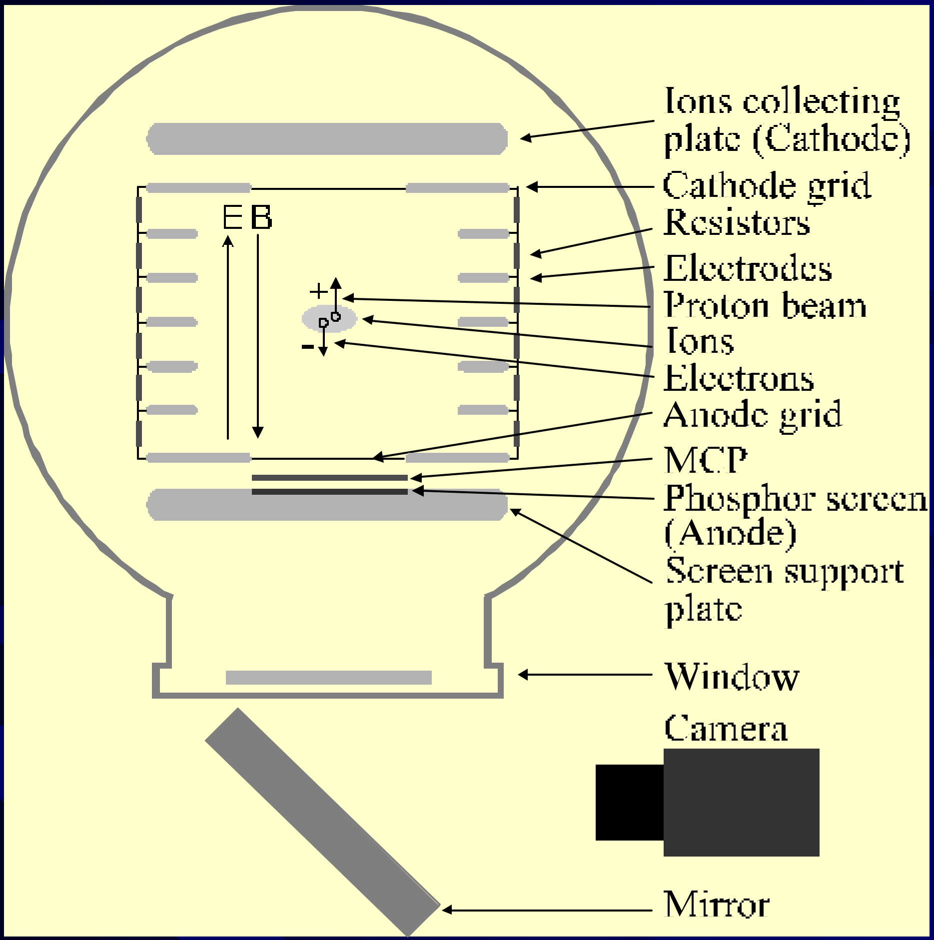
→ when:

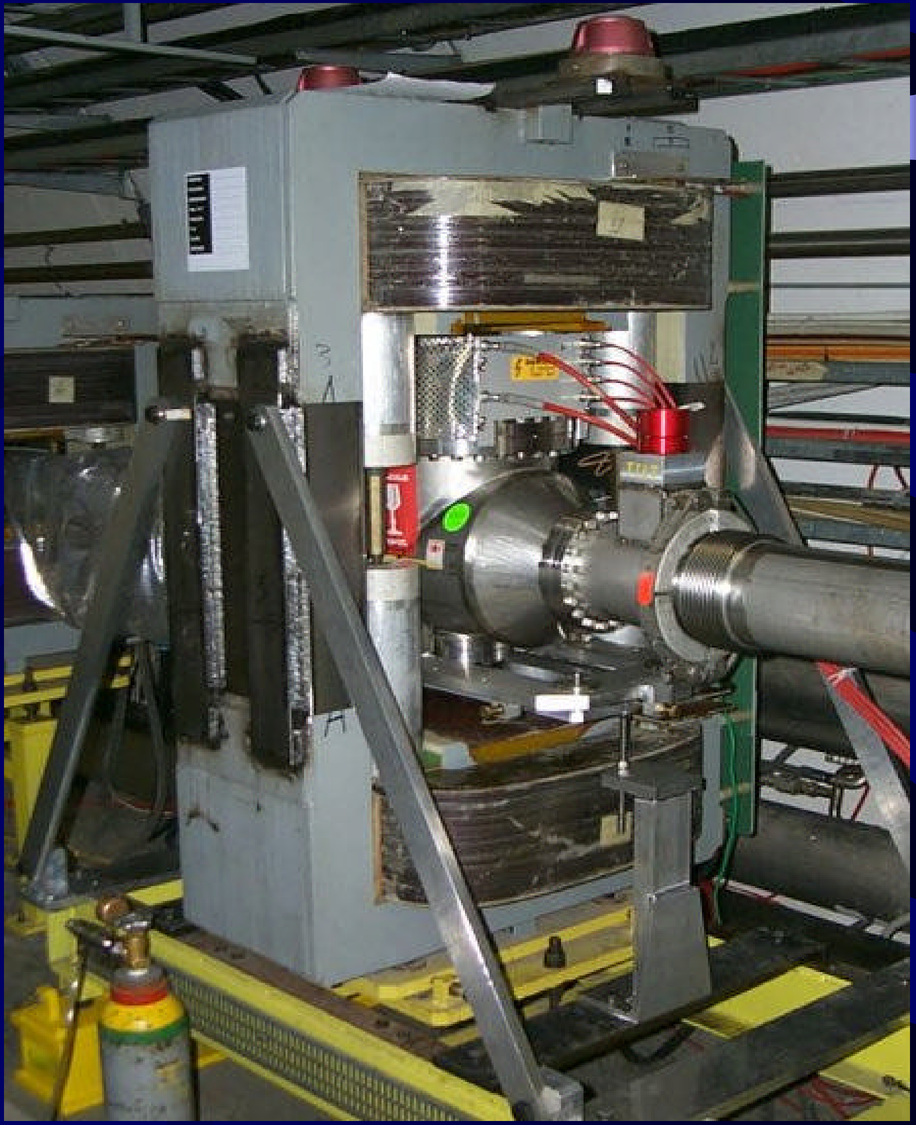
1) at the moment of injection
2) with circulating beams

Measuring Beam Size

- Beam Profile Measurements in the LHC
  - → Workhorses
    - Synchrotron light monitor
    - Wire scanners for cross calibration
  - → For injection
    - OTR screens
  - → For ions
    - IPM (& as back-up for SR monitor)

(Rest Gas) Ionisation Profile Monitor - IPM

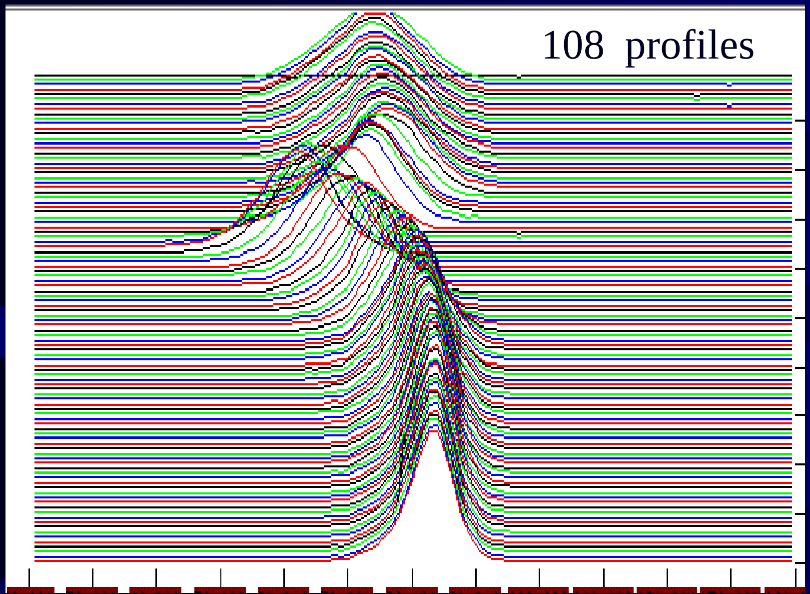


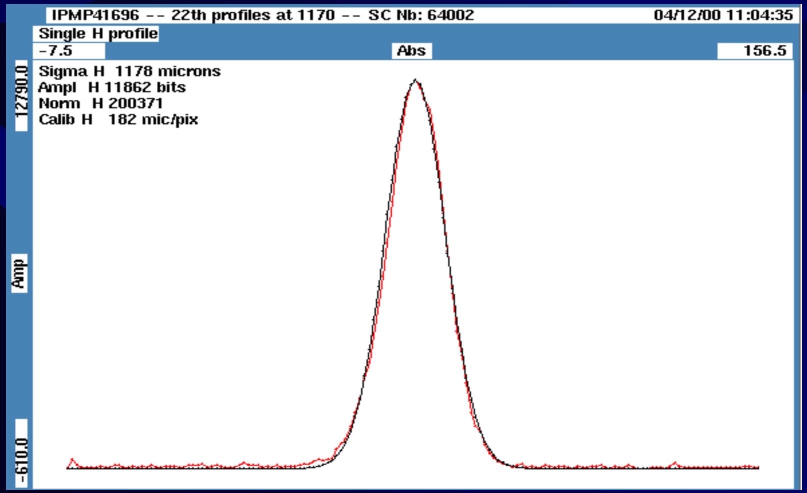


IPM Single Bunch Measurements

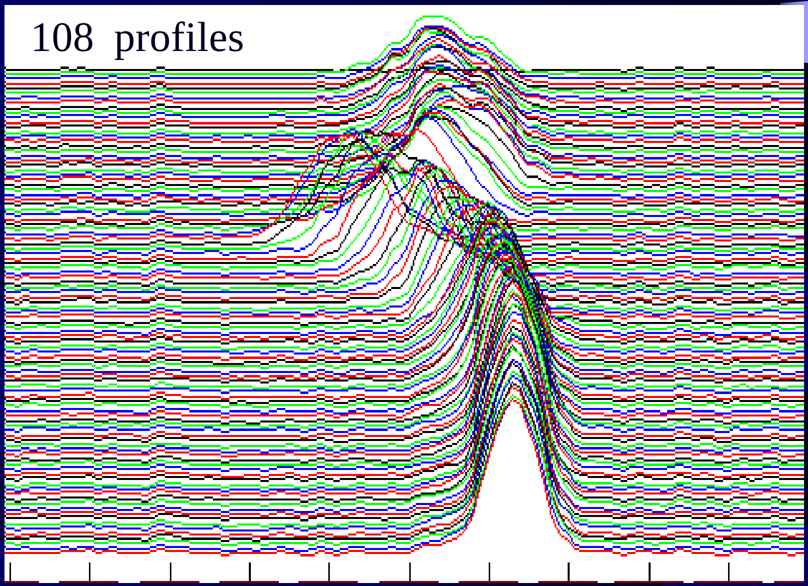
(CCD - 870 SPS turns (20 ms) per profile)

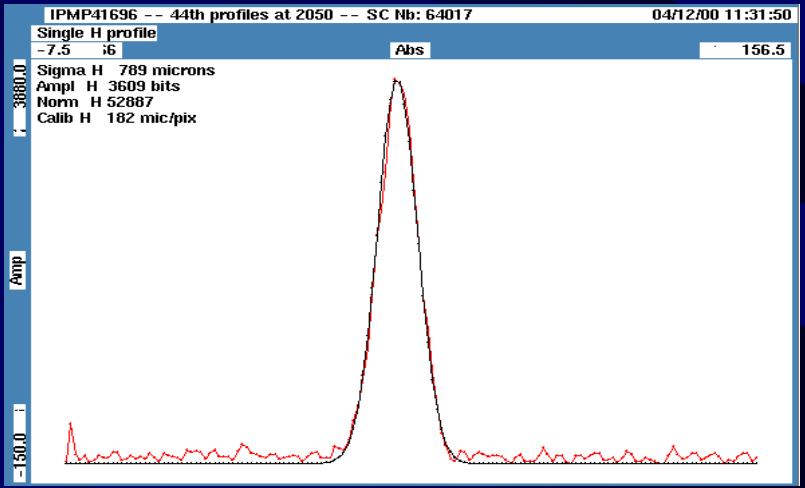
6×10^{10} p/bunch





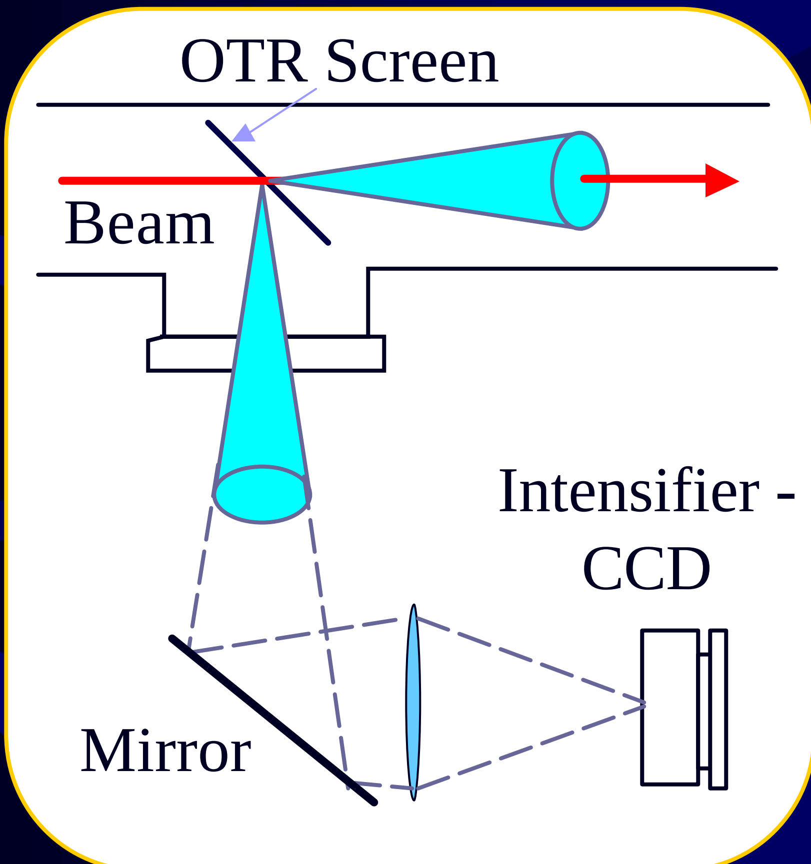
2×10^{10} p/bunch

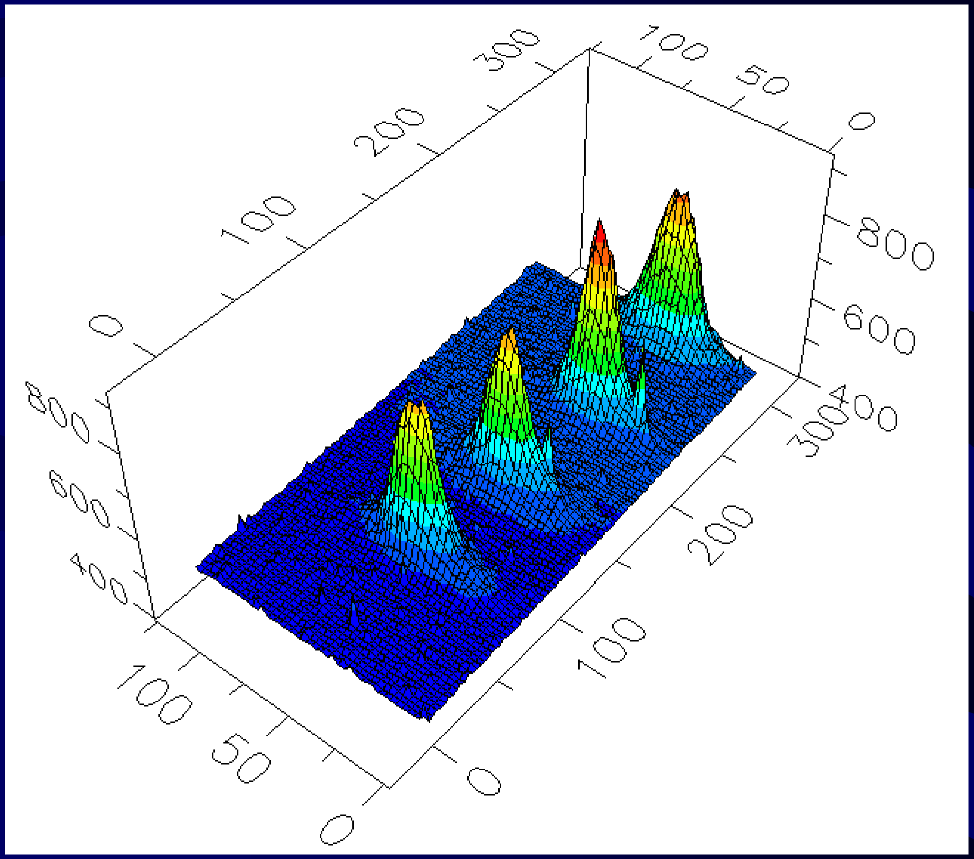




Optical Transition Radiation Monitors

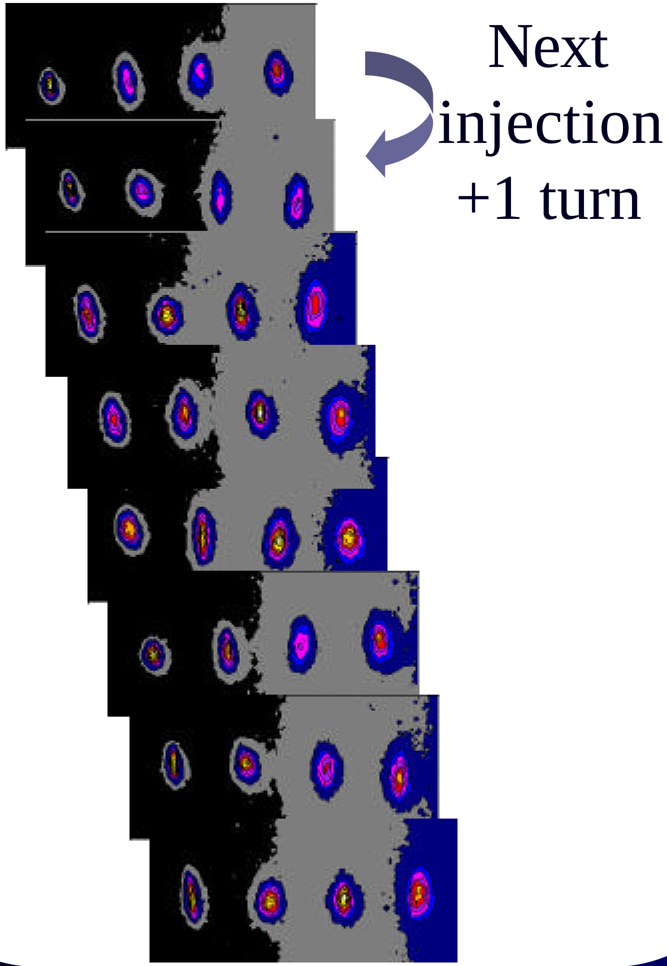
As Beam hits the 12μm Titanium foil 2 cones of radiation are emitted

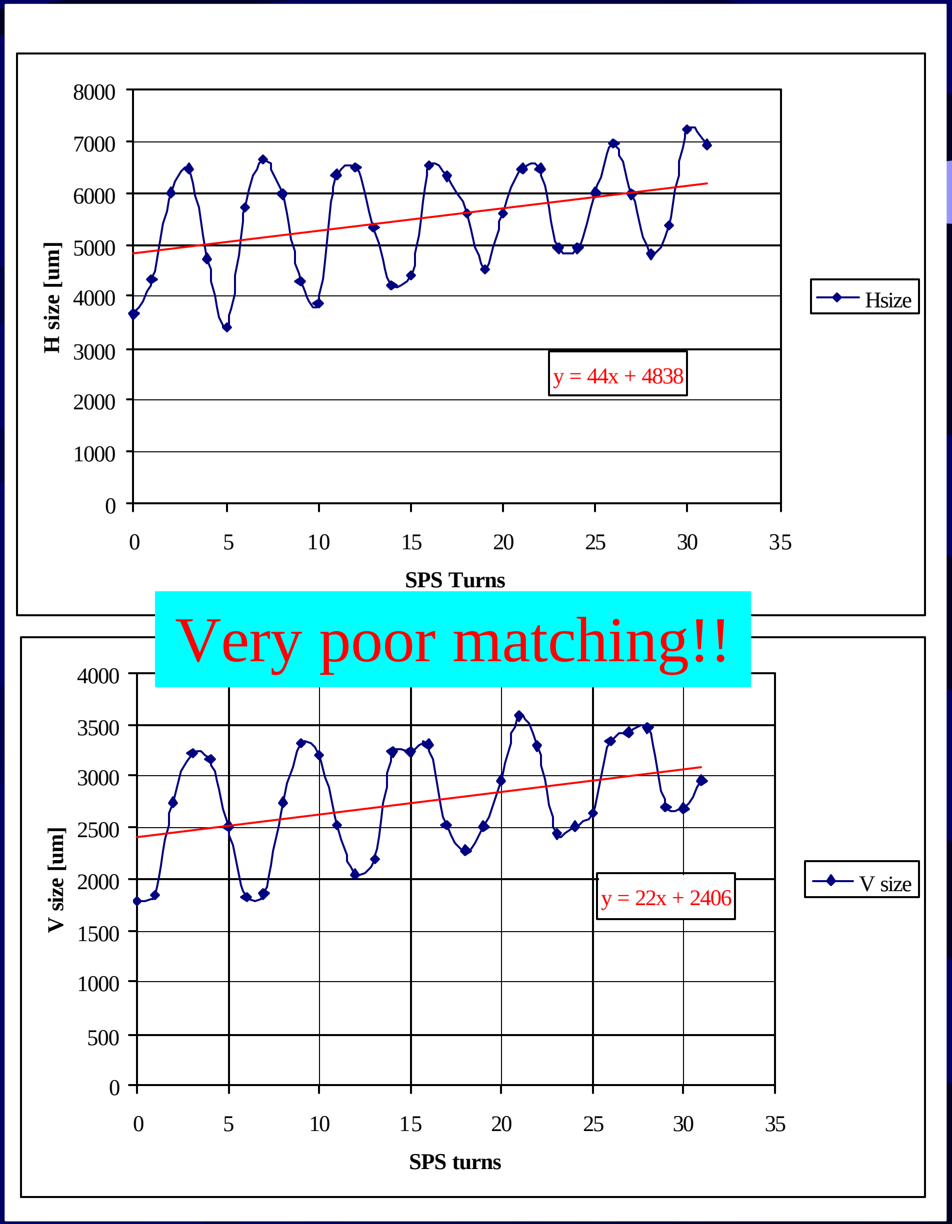




Capturing emitted radiation on a CCD gives 2D beam distribution

Turn-by-Turn OTR Results





β-Mismatch at injection seen as a beating in the beam profile

Commissioning The LHC

(M. Lamont AB/OP – LHC Workshop, Jan 2005)

Commissioning the LHC with beam
Stage One

- Establish colliding beams as quickly as possible
- Safely
- Without compromising further progress

Take two moderate intensity multi-bunch beams to high energy and collide them.

Beam Types for Commissioning

- Pilot Beam:
  - →Single bunch, 5 to 10 x 10^9 protons
  - →Possibly reduced emittance
- Intermediate single:
  - →3 to 4 x 10^{10} ppb
- 4 bunches etc. pushing towards…
- 43 bunches
  - →3 to 4 x 10^{10} ppb

First turn

- Commission injection region
- Instrumentation
- Threading

PILOT

RING 1
RING2

Establish circulating beam

- Circulating low intensity beam

PILOT

RING 1
RING2

450 GeV Initial

- Polarities and aperture checked.
- Basic optics checks performed.
- First pass commissioning of BI performed.
- Phase 1 of machine protection system commissioning performed. .
- Beam Dump commissioned with beam

SINGLE
INTERMEDIATE

RING 1
RING2

450 GeV Detailed

- Well-adjusted beam parameters, detailed optics checks
- Fully functioning beam instrumentation.
- Machine protection as required for ramp
- RF - beam control loops operational and adjusted

SINGLE
INTERMEDIATE
++

RING 1
RING2

Two beam operation

- 2 beams, well-adjusted beam parameters,
- beam instrumentation, cross talk etc.

Switch to nominal

- 2 beams, well-adjusted beam parameters,
- beam instrumentation, cross talk etc.

Snapback

PILOT++

RING 1
RING2

- Single beam, good transmission through snapback
- Requisite measurements (orbit, tune, chromaticity)

Ramp Single Beam

PILOT++

RING 1
RING2

- Single beam, good transmission to top energy
- Commission beam dump in ramp
- Stops in ramp - measurements
- RF

Two beams to top energy

43 x 43

COLLIDE

- Two beams, good transmission to top energy
- Measurements

Squeeze

SINGLE INTERMEDIATE

RING 1
RING2

- Single beam - step through squeeze
- Parameter control, measurements

At each phase:

- Equipment commissioning with beam
- Instrumentation commissioning
- Checks with beam
  - →BPM Polarity, corrector polarity, BPM response
- Machine protection
- Beam measurements
  - →beam parameter adjustment, energy, linear optics checks, aperture etc. etc.

Instrumentation – the essentials

(H. Schmickler AB/BDI – LHC Workshop, Jan 2005)

- First turn i.e. immediately
  - → Screens, BPMs, fast BCT, BLMs
- Circulating beams at 450 GeV
  - → BPMs, DC BCT & lifetime, BLMs
  - → Tune & chromaticity
  - → Emittance: wire scanners..
- Snapback and Ramp
  - → Continuous Tune & Chromaticity
  - → Orbit
  - → BLMs to beam interlock controller etc.

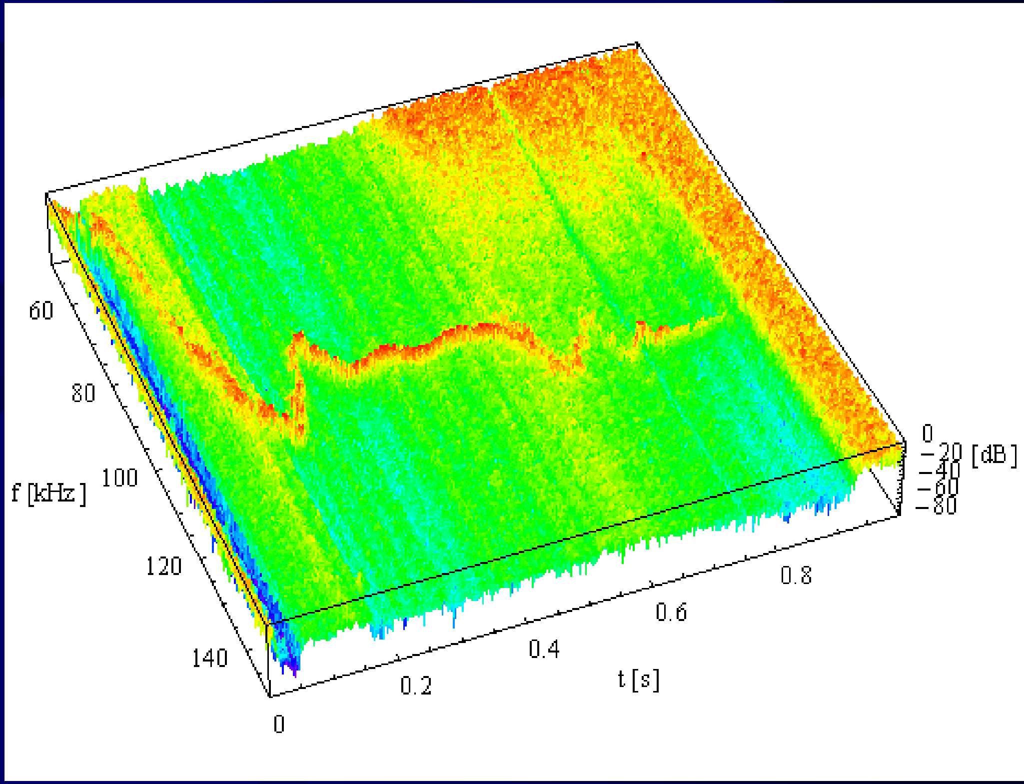
Beam Commissioning: Tune measurement

Day 1 - Time resolved measurements:

- sequence of kick stimuli (2Hz) with FFT based tune measurements
- provides more information than a PLL trace and will be available from the start.

PLL tune tracking:

- The PLL will need at least a few weeks to be set up
- US-LARP collaboration ongoing.
- Difficult to say when first system will be operational. Compatibility with transverse damping so far unclear.



Beam Commissioning: Chromaticity

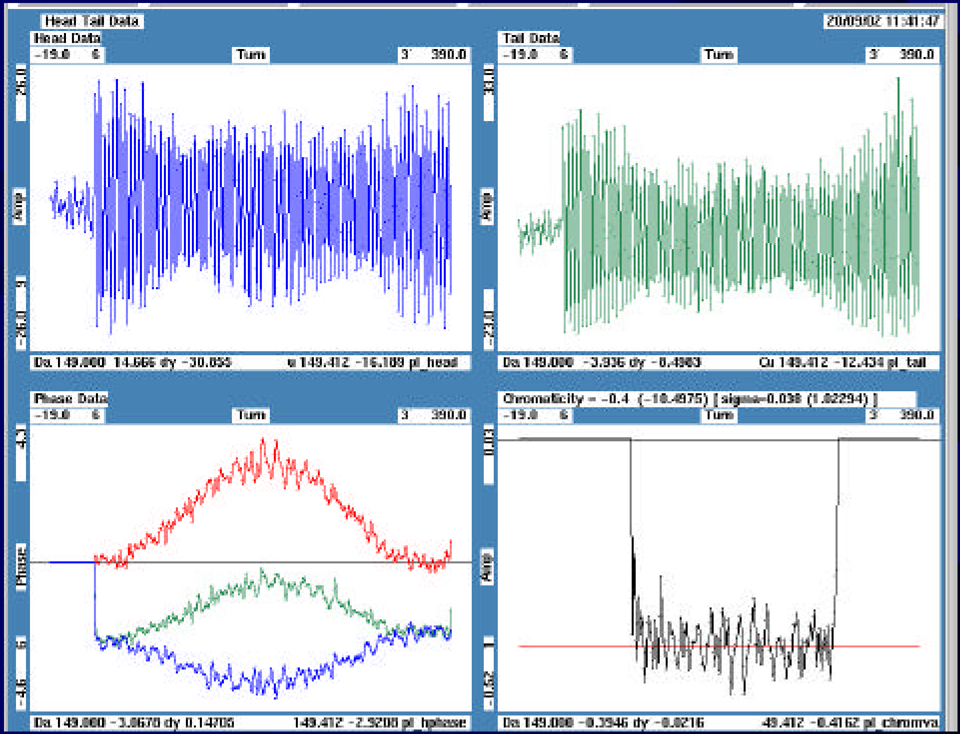
Day 1 - Head-Tail analysis

- sequence of kick stimuli (2Hz) with head-tail based Q' measurements
- requires beam synchronous timing
- betatron oscillation has to last at least 50% of a synchrotron period.

Alternative: difference in tune for two discrete settings of beam momentum

PLL tune tracking:

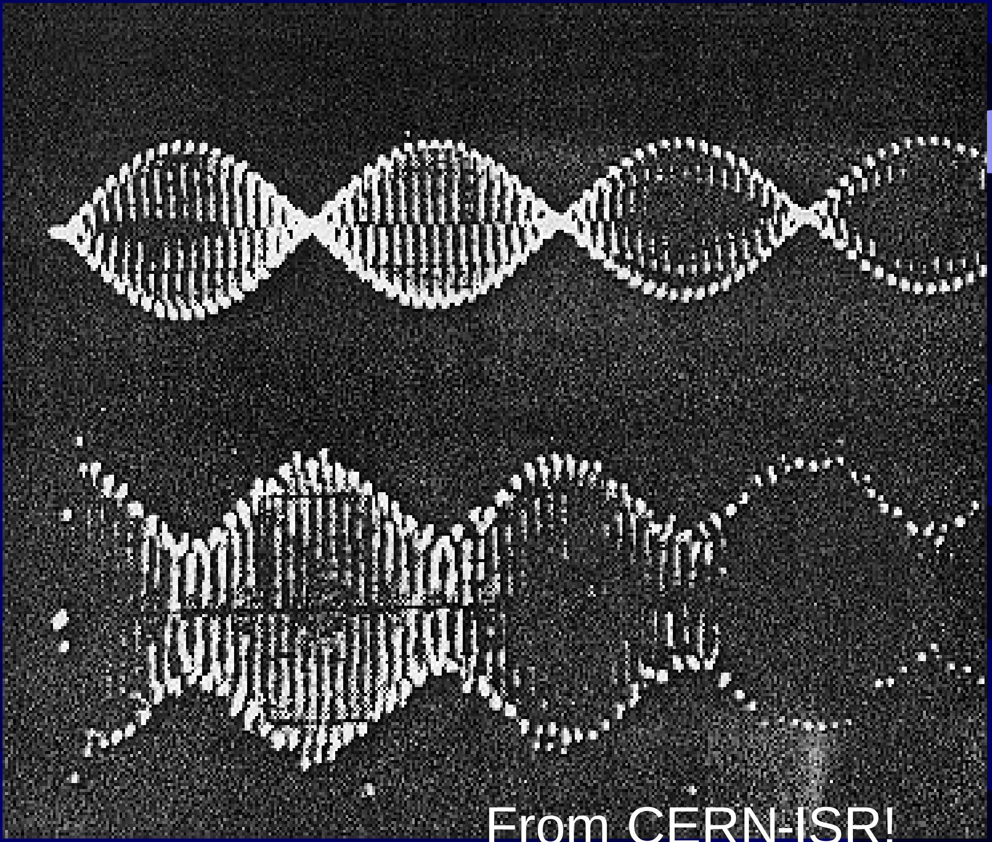
- Chromaticity tracking via periodic momentum modulation will be available as soon as the PLL works.



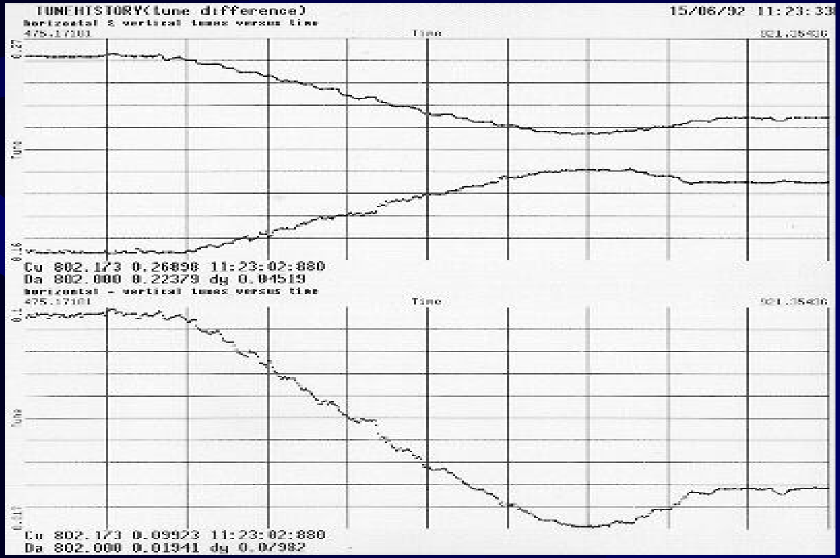
Beam Commissioning: Chromaticity

Day 1

- Again kick as beam stimulus.
- Coupling (in particular if large) from cross talk to other plane



From CERN-ISR!



Day N

- with PLL available: closest tune approach measurement

Transverse Diagnostics: Summary

- Clear two step approach:
  1) Day 1 with kicked beams and classical motion analysis
  2) Day N with PLL and more powerful time resolved methods

- This puts a high pressure on getting dedicated machine time in order to commission the PLL early.

- As long as emittance growth is not the major concern, the problems will be:
  - $\rightarrow$ automation of parameter settings depending on beam conditions
    - filters, gain switches, timings etc
    - phase scans in order to determine the correct PLL lock conditions

- For operational beams the additional problems will be:
  - $\rightarrow$ lowering the excitation level to an insignificant level
  - $\rightarrow$ coping with coupling
  - $\rightarrow$ achieving compatibility with resistive transverse damping