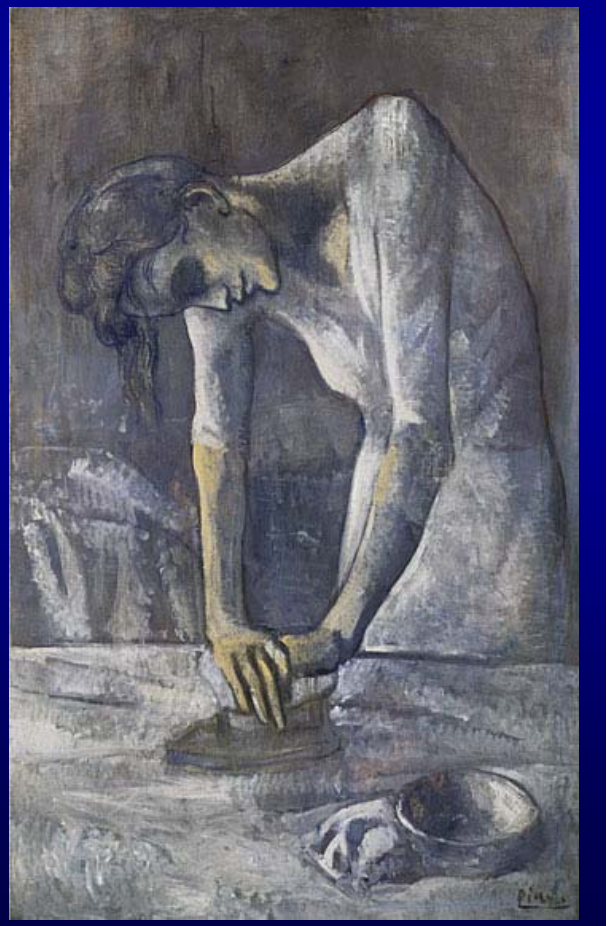
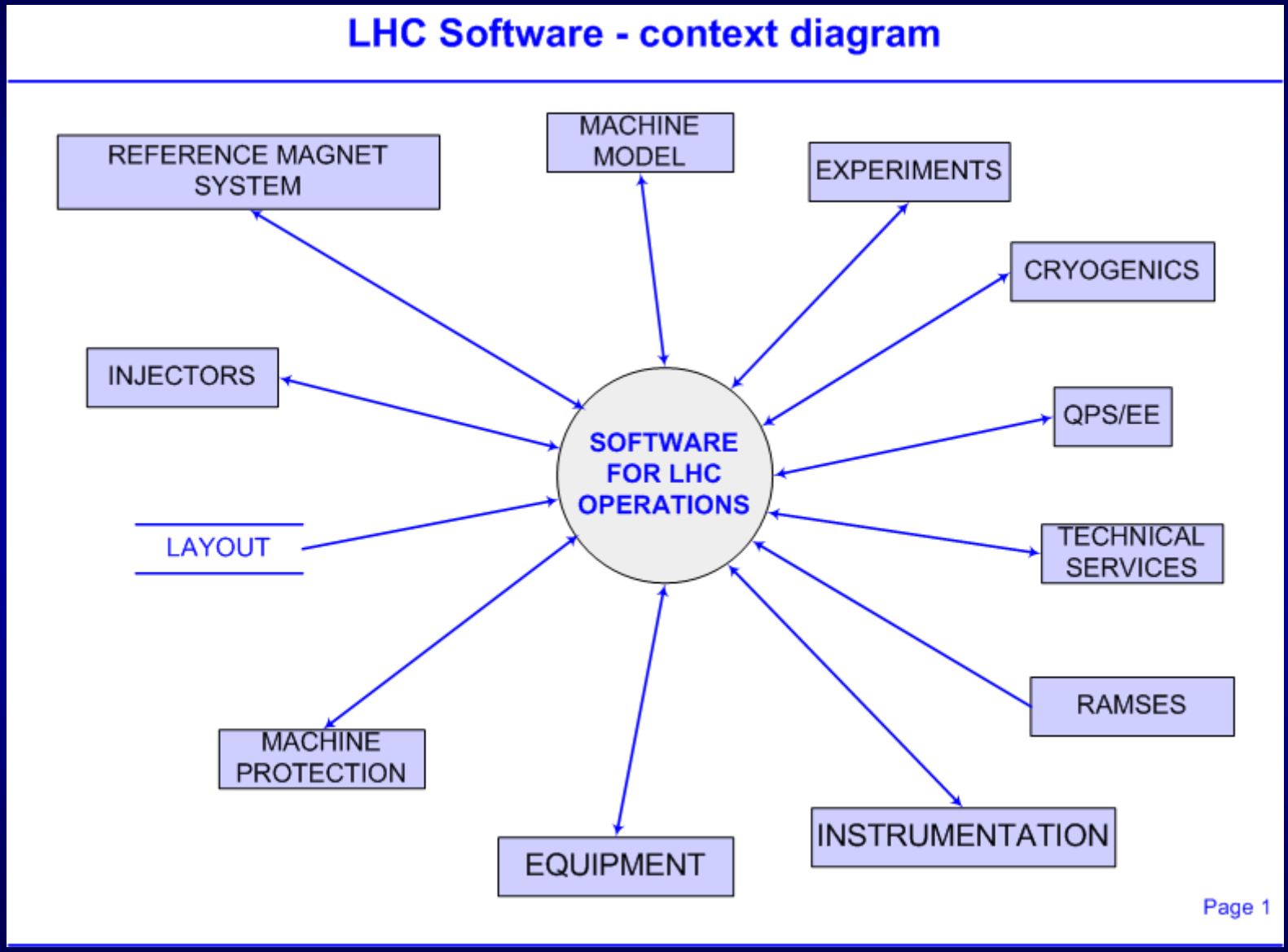
LHC Application Software
User perspective

21 / 09 / 2005

Mike Lamont

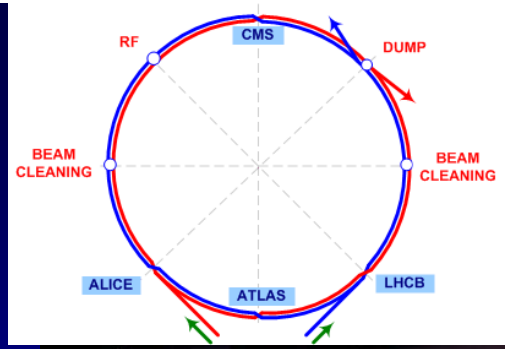


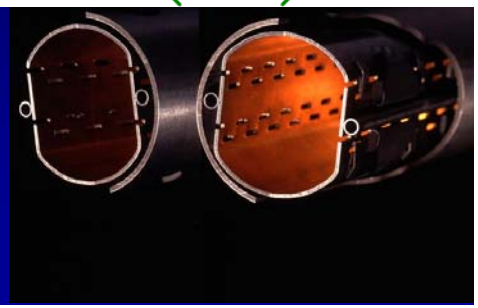
Context

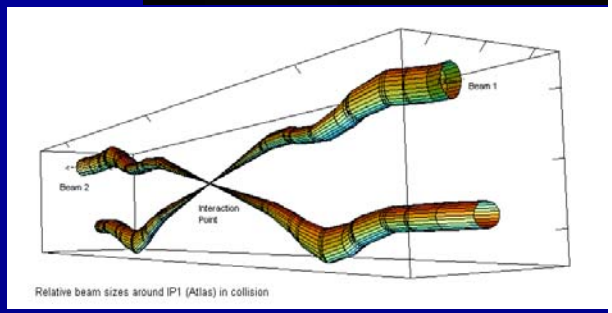

LHC Software - context diagram
REFERENCE MAGNET SYSTEM
MACHINE MODEL
EXPERIMENTS
CRYOGENICS
INJECTORS
QPS/EE
SOFTWARE FOR LHC OPERATIONS
LAYOUT
TECHNICAL SERVICES
RAMSES
MACHINE PROTECTION
EQUIPMENT
INSTRUMENTATION
Page 1

Challenge

- We have to whizz 2 beams of 100,000,000,000 high energy protons in opposite directions around a 27 km ring
- Through two very small, very cold holes
- Squeeze ‘em down to 16 microns, get them to collide and keep ‘em colliding for something like 10 hours
- While keeping our losses down to ridiculously low level







Relative beam sizes around IP1 (Atlas) in collision

AND WE GOT A DO IT WITH YOUR CONTROL SYSTEM

The controls' challenge

- **EQUIPMENT**
  - Collimators/TDI/TCDQ etc.
  - Beam Dump
  - Power converters,
  - Kickers
  - RF, TFB, LFB
  - Spectrometers & compensation
- **INSTRUMENTATION**
  - Distributed systems:
    - BLMs, BPMs,
  - Standalone:
    - BCT, BTV, AGM, BIPM, BWS, Schottky..
  - Tune, Chromaticity, Coupling
  - Luminosity monitors
  - Radiation Monitors
- **MAGNETS – RMS, errors**
- **MACHINE PROTECTION**
- **VACUUM, CRYOGENICS, QPS, EE**
- **EXPERIMENTS**

⊗

Settings, functions, monitoring, display, post mortem, control, acquisition, concentration, archiving, alarms, interlocks

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⊗

Driving the machine through the cycle

Magnet errors, crossing angles, snapback, ramping, squeezing, colliding, orbit, parameter control, optimisation etc. etc.

Controls

- **The high level control system shall performs the following functions**
  - **Monitoring, recording and logging of accelerator status and process parameters;**
  - **Display of operator information regarding the accelerator status and beam parameters;**
  - **Provision of operator controls to affect changes to the accelerator;**
  - **Automatic process control and sequence control during all beam related modes of operation and covering all operational scenarios i.e. control within normal operating limits;**
    - **Commissioning**
    - **Physics (proton-proton, ion-ion, TOTEM..)**
    - **Machine development**
    - **Fault diagnostic and recovery**
  - **Prevention of automatic or manual control actions which might initiate a hazard.**
  - **Detection of onset of hazard and automatic hazard termination (i.e. dump the beam), or mitigation (i.e. control within safe operating limits)**

1. Equipment subsystems

- **Operational settings management:**
  - Facilities for the settings changes of all individual equipment systems
  - All settings changes shall be recorded at the application layer through accelerator wide standard application programs.
  - All state changes shall be recorded
  - Control appropriate to accelerator modes
- **Equipment settings management**
  - are managed by the equipment experts.
- **Equipment state change**
  - All states changes to be recorded
- **Equipment monitoring**
  - Standard facilities for display, browsing and analysis
- **XPOC**
  - A set of signals are also acquired and analysed on a shot-by-shot basis at each injection to continuously monitor the injection kickers with the objective to detect any degradation of their performance.

Collimators & Absorbers

2 jaws per collimator, 2 motors per jaw, 500 degrees of freedom with extreme accuracy (& reliability)

EQUIPMENT

- **Dedicated application/software**
  - Settings, optimisation
  - with respect to closed orbit, beam size
- **Automated set-up process**
  - interface with beam loss system
- **Ramp & Squeeze**
  - Functions
- **Fixed displays – logging – post-mortem – alarms**
- **Interface to Safe Settings**
- **Interface to sequencer**

TCDI, TDI, TCLI, TCT, TCDQ, TCSG, TCP, TCS, TCLP, TCLA, TCHS, Roman Pots

LHC injection kickers

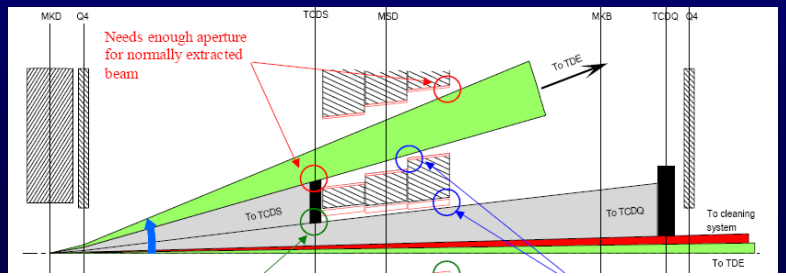
EQUIPMENT

- High level application
  - Shall allow traversal of system state transition diagram
  - Settings management (including usual trim/archive functionality)
  - Injection and dump mode management
- Definition of operational state diagram taking into account external conditions – interface to sequencer
- Verification of proper receipt of pre-pulses & slow timing
- Visualization of kicker waveform (shall be recorded every cycle)
- XPOC: Post Operation Checks
  - Typical signals acquired are the magnet current pulse shape, the currents of the injected and circulating beams, and the beam permit and beam abort gap signals
- Safe settings management
- Post Mortem - Logging – Alarms – Visual confirmation of states

LHC Beam Dump System

EQUIPMENT

- **Application for basic control and diagnostics**
  - Kicker: safe settings management no trim possibilities for operators. Status. Synchronisation.
  - Record all manipulations
  - Septa: FGC plus all associated functionality but current tracked again. current reference dealt with by us. No trimming outside tolerances.
- **Inject and dump mode**
- **Operational State**
  - On, reset, check, validation dump.
  - Access into zone: re-close, check, validation dump,
  - Test sequences
- **XPOC**
  - Check kicker pulse against extracted beam etc.
  - Extraction channel instrumentation monitoring



LHC Power converters

EQUIPMENT

- **Full integration into settings management**
  - Intimately involved in 95% of all trims
  - Injection plateau, ramp & squeeze functions
- **Real-time**
  - Feedback actuators
- **State control**
- **Monitoring**

- **Post Mortem – Alarms – Logging – Fixed Display**

		No. of Magnets	Aperture
Dipole	MB	1232	twin
Lattice quadrupoles	MQ	392	twin
Lattice sextupoles	MS	688	single
Lattice Octupoles	MO	168	twin
Skew quad	MQS	32	twin
Arc skew sext	MSS	64	single
Tuning trim quad	MQT	160	twin
Octupole spool pieces	MCO	1232	single
Decapole spool pieces	MCD	1232	single
Sextupole corrector (b3) in MBA & MBB (spool piece corrector)	MCS	2464	single
Insertion region long trim quads	MQTLI	36	twin
Arc dipole corrector	MCBH	376	single
Arc dipole corrector	MCBV	376	single
Twin aperture separation dipole in IR (194mm). D4	MBRB	2	twin
Twin Aperture Separation dipole in IR(188mm). D2	MBRC	8	twin
Single Aperture Separation dipole. 1 MBRS magnet on each beam - one cry	MBRS	4	single
Single aperture separation dipole. D1 in IR2 and IR8	MBX	4	single
Twin aperture warm dipole. D3 and D4 in IR3 and IR7	MBW	20	twin
Single aperture warm dipole. D1 in IR1 and IR5 (6 each side)	MBXW	24	single
Matching correction dipole	MCBCH	80	
Matching correction dipole	MCBCV	80	
Inner Triplet Horizontal dipole corrector,	MCBXH	24	single
Inner Triplet vertical separator	MCBXV	24	single
Single aperture, horizontal, warm dipole corrector	MCBWH	8	
Single aperture, vertical, warm dipole corrector	MCBWV	8	
Matching section dipole orbit corrector	MCBYH	44	single
Matching section dipole orbit corrector	MCBYV	44	single
Skew octupole spool-piece (a4) associated to MQSX in MQSXA	MCOSX	8	single
Octupole spool-piece (b4) associated to MQSXA	MCOX	8	single
Quadrupole in the insertions (3.4 m)	MQM	46	twin
Quadrupole in the insertions (4.8 m)	MQML	36	twin
Wide aperture quadrupole in the insertions, twin aperture	MQY	24	twin
Quadrupole in the insertions (2.4 m)	MQMC	12	twin
Twin aperture warm quadrupole in IR3 and IR7. Asymmetrical FD or DF	MQWA	40	twin
Twin aperture warm quadrupole in IR3 and IR7. Symmetrical FF or DD	MQWB	8	twin
Inner triplet quadrupole, single aperture (Q1, Q3)	MQXA	16	single
Inner triplet quadrupole, single aperture (Q2)	MQXB	16	single
Skew sextupole spool-piece (a3) associated to MQSX in MQSXA	MCSSX	8	single
Sextupole spool-piece (b3) associated to MCBXA	MCSX	8	single
	MQRL	4	twin
	MQR	4	twin
Dodecapole spool-piece (b6) associated to MCBXA	MCTX	8	single
Skew quadrupole (a2) in MQSXA	MQSX	8	single
	MCBWB	1	
	MU	8	
Magnet for Gas Monitoring in IR4, Vertical Plane	MGMWV	1	
Magnet for Gas Monitoring in IR4, horizontal Plane	MGMWH	1	
Alice spectrometer			
LHCB spectrometer	MBAW	1	
Alice comp	MBLW	1	
LHCb comp	MBWMD	1	single
	MBXWH	1	single
Alice comp	MBXWS	2	
Injection septa	MSIA	4	
Ejection dump septa	MSIB	6	
Ejection dump septa	MSDA	8	
Ejection dump septa	MSDB	10	

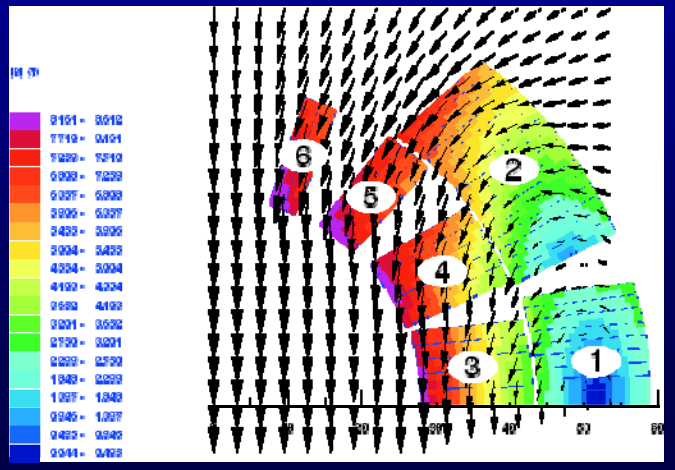
MAGNETS

All 9000+

Monitoring

Logging

Interlock status



LHC RF

EQUIPMENT

- All equipment shall be controllable from main operational software
  - Function generation provided by FGCs from AB/PO.
  - Schneider PLCs for control & surveillance of power equipment (klystrons, power supplies etc.)
- High bandwidth remote acquisition: (OASIS)
  - Mountain ranges, analog signals, time waveforms, phase loop, injection transient signals. APW wideband longitudinal pickups, first N turns, injection
- The system shall use the standard high level settings management facilities:
  - control of phase, frequency, voltage etc.
- Traversal of state transition diagram
  - RF line and module control
- Fast synchronization signals – diagnostics
- Low level control
  - Cavity control – STD – settings – fast feedback & tuning
  - Beam control – synchro, phase, radial loops
- Longitudinal feedback:
  - feedback response, monitoring and control – STD & functions
- Alarms, Logging & Post-mortem
  - Unit control, state, status
  - LFB, Capture, Mountain range
  - Bunch length
  - Timing signals, injection requests
  - Low level, diagnostics, alarms…

LHC TFB

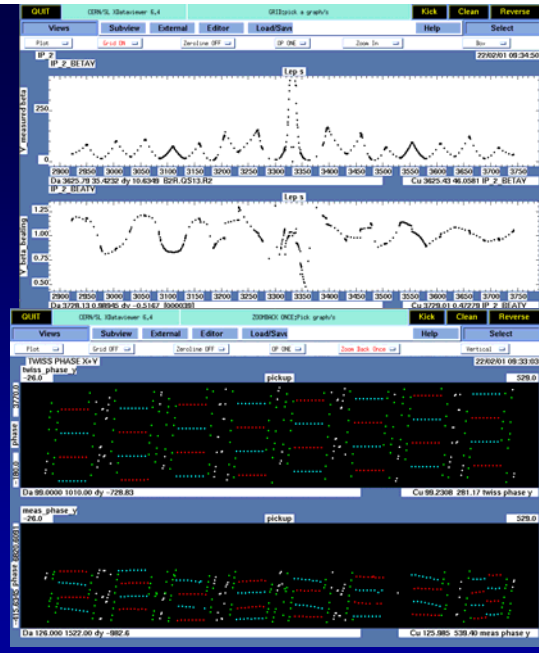
EQUIPMENT

- **Stand alone application:**
  - **STD**
  - **Parameter control, settings management**
  - **Fully integrated into high level system**
- **XPOC – Diagnostics**
  - **Analog acquisition – 1000 turns 64 channels**
  - **10 mega –samples per channel**
  - **Plus Analysis tool!**

2. Beam Instrumentation

- **Control and settings changes of all instrumentation**
  - All settings changes shall be recorded
  - All state changes shall be recorded
- **Acquisition**
  - On-demand or subscription
  - Configurable (beam, bunch etc.)
  - Have to pull together distributed measurements into logical whole (e.g. orbit) and re-publish result.
- **Measurements**
  - All measurements to be recorded together with measurement parameters
  - Standard facilities for display, browsing and analysis
  - Archiving, references etc.
  - Access for post-mortem, post-run analysis, web access etc.
- **Synchronised measurement acquisition as part of scans, feedback, or at given point in the cycle.**
- **Slow timing triggered acquisition. Integration in measurement procedures - scans and stuff**

BPMs

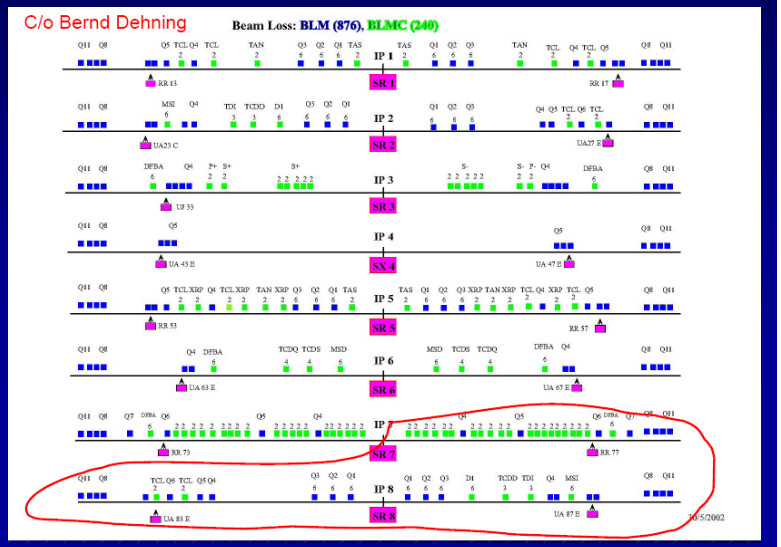


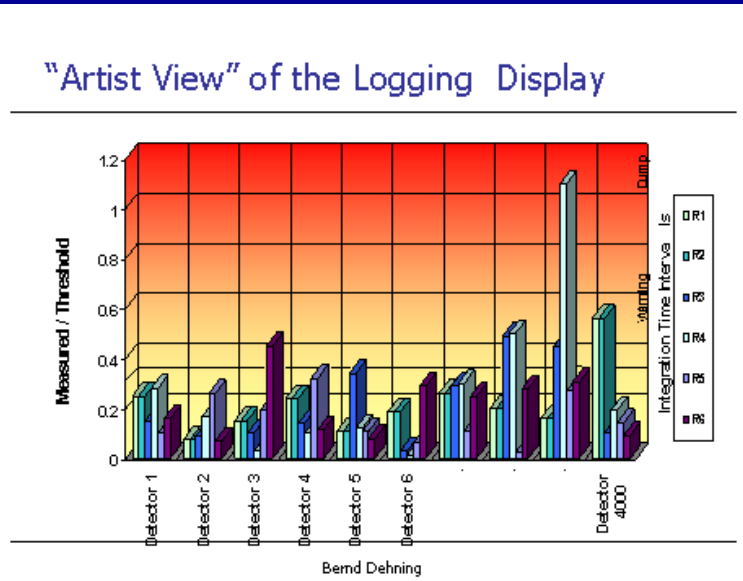
- CONCENTRATION
- First turn
  - Trajectory acquisition
  - Threading
  - Turn by turn over first N turns
  - Closure
  - Injection point correction
- Orbit
  - Acquisition, orbit correction, average, difference
  - Harmonic analysis
  - Energy measurement, mis-match, adjustment using correctors etc.
  - Sum signal of BPMs etc.
  - 1000 / 100000 turns: archive, display, analysis
  - Beta beating analysis, phase advance
  - Derivatives: crossing angles, beam separation, IP optimisation
  - Bunch by bunch derivatives: transverse position along a batch,
- Going to have to deal intelligently with the parts of the two rings in common, the various separation and crossing-angle bumps plus spectrometer magnet compensation etc.

INSTRUMENTATION

BLMs

- Concentration
- Threshold management system
- Logging
- Post-mortem
- Fixed Display
- Incorporation into optimisation procedures
- RT feed

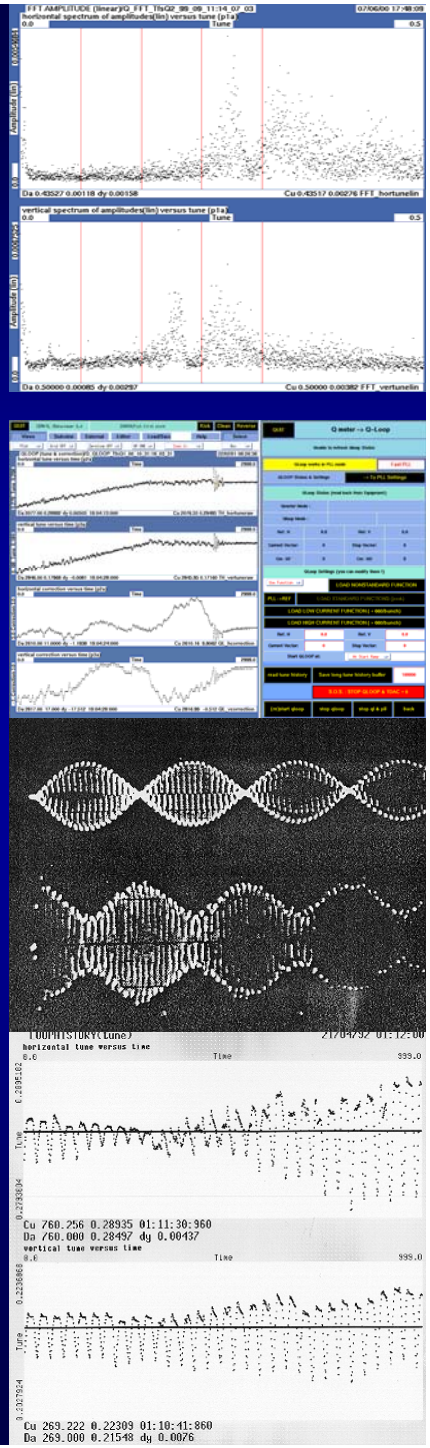




INSTRUMENTATION

Plus

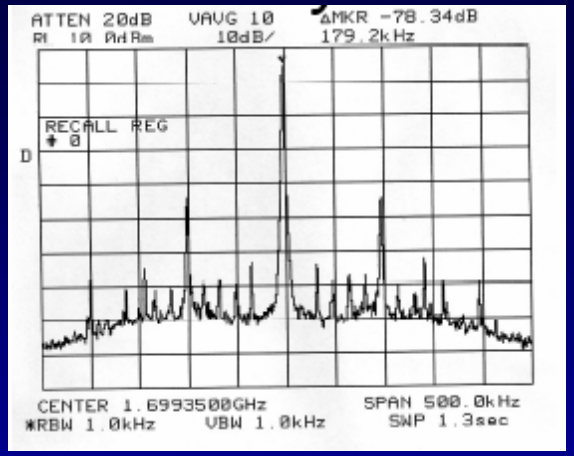
- **BCT**
  - PM – Logging – FD – Measurement
- **BTV**
  - Acquisition, display, control. Screen state control,
  - parameter adjustment interlocks with respect to beam condition
  - Analysis: fitting, emittance
  - PM – Logging – FD – Measurement
- **Tune measurement**
  - Dedicated application, Q kicker control,
  - different modes: PLL. FTT
  - Feedback
  - Analysis,
  - PM – Logging – FD – Measurement
- **Chromaticity measurement**
- **Coupling measurement**

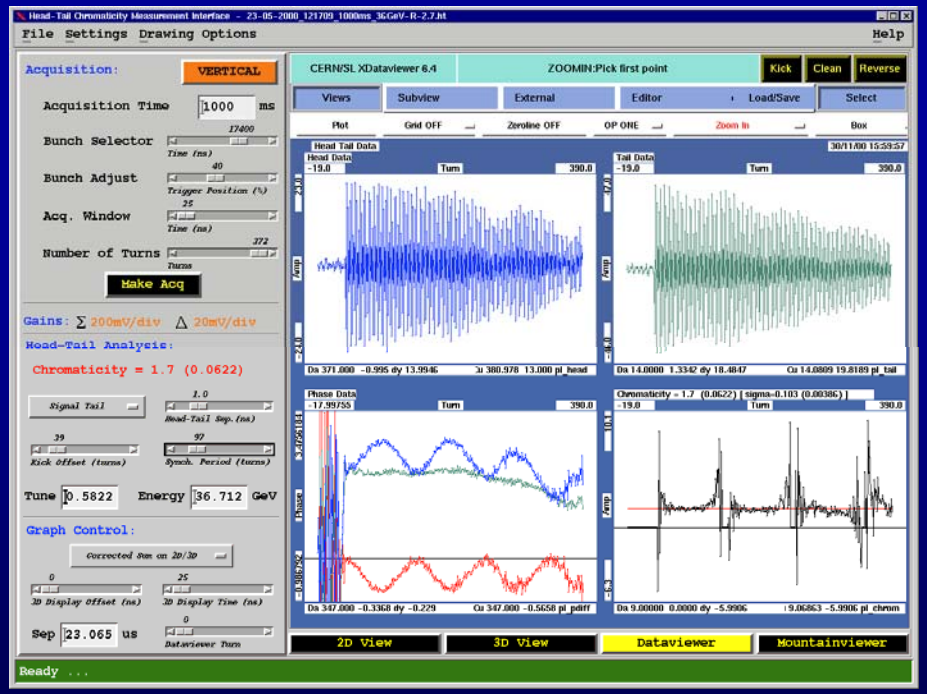


INSTRUMENTATION

Plus

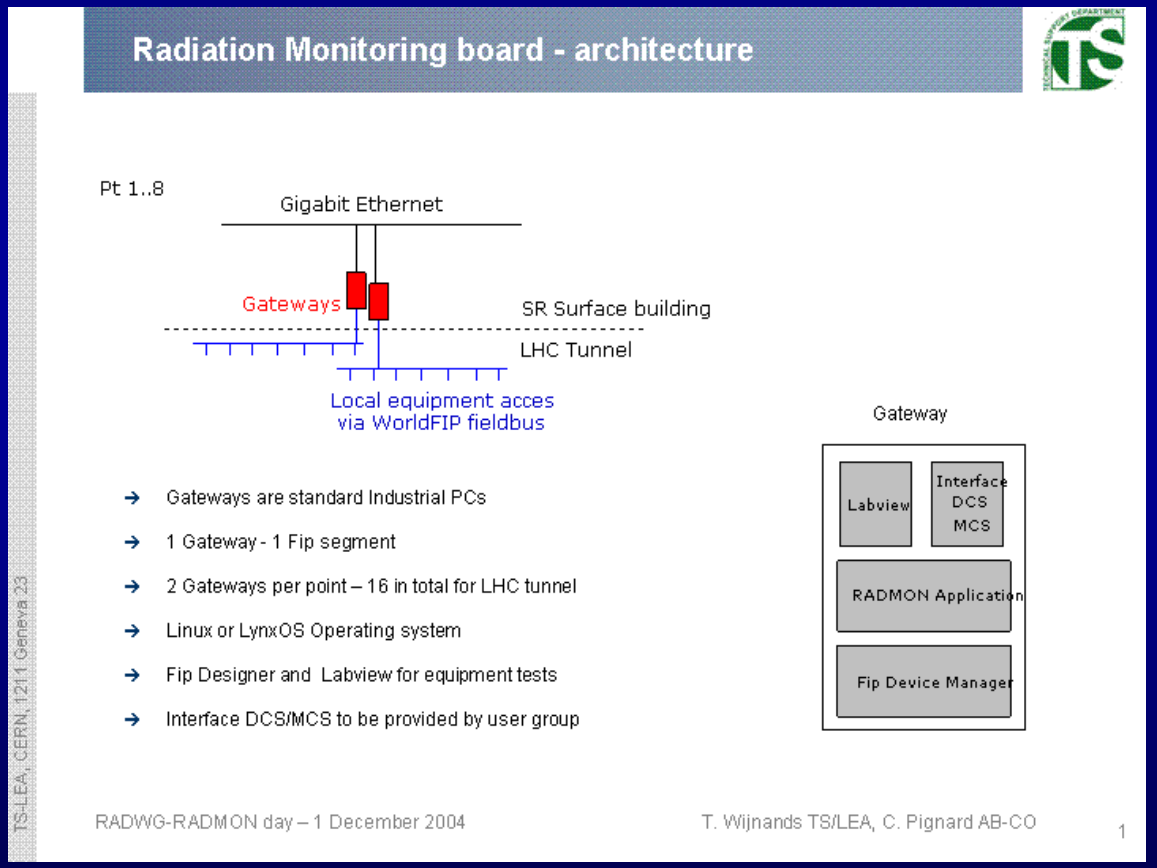
- Schottky
- Wire-scanners
- RGM
- Abort gap monitor
- Luminosity monitors
- BST – diagnostics
- K-modulation
- Head-tail chromaticity





CO RADIATION MONITORING

- **PM – Logging – FD**

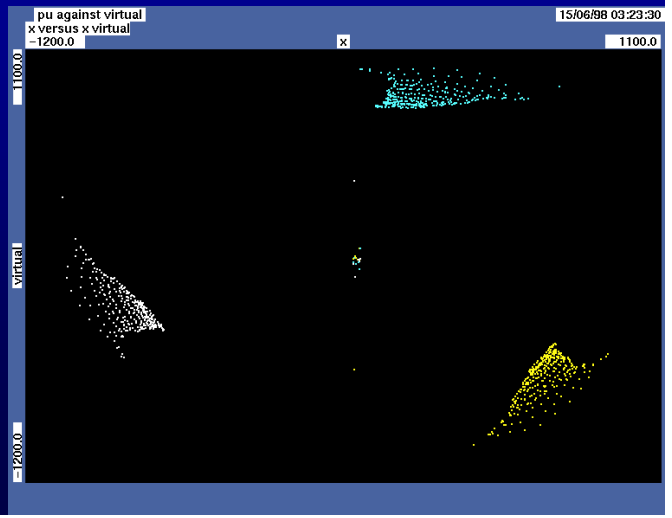


Combined 1&2

Measure & correct or twiddle and measure

- **For example:**
  - Orbit and trajectory correction
  - Chromaticity - via RF frequency modulation
  - Dynamic aperture measurements using kickers
  - Momentum – sector to sector dispersion
  - Beam Loss Monitors v collimator positions, bumps etc
  - Beam Current Transformer (IBMS) - lifetime v bumps
  - Beam Profiles measurement - matching

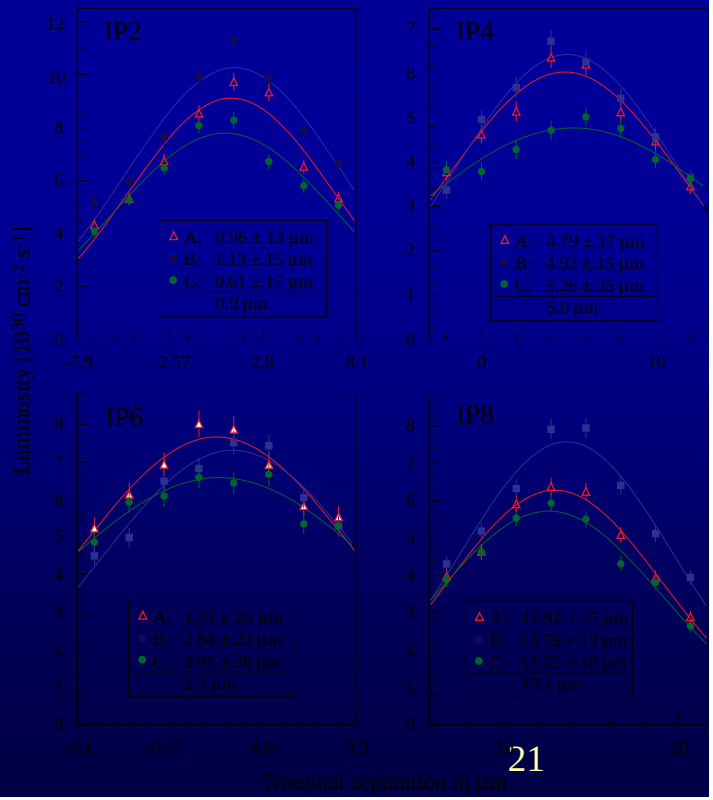
Etc……



Combined 1&2: Measure & correct and/or process

MEASURE & CORRECT

- **SCANS – COMPLEX MEASURE/TRIM PROCEDURES**
  - Collision
  - Luminosity optimisation
- **DERIVED QUANTITIES**
  - Beam-beam footprint
  - Beam size transposition
  - Emittance
- **ANALYSIS TOOLS**
  - Beta beating



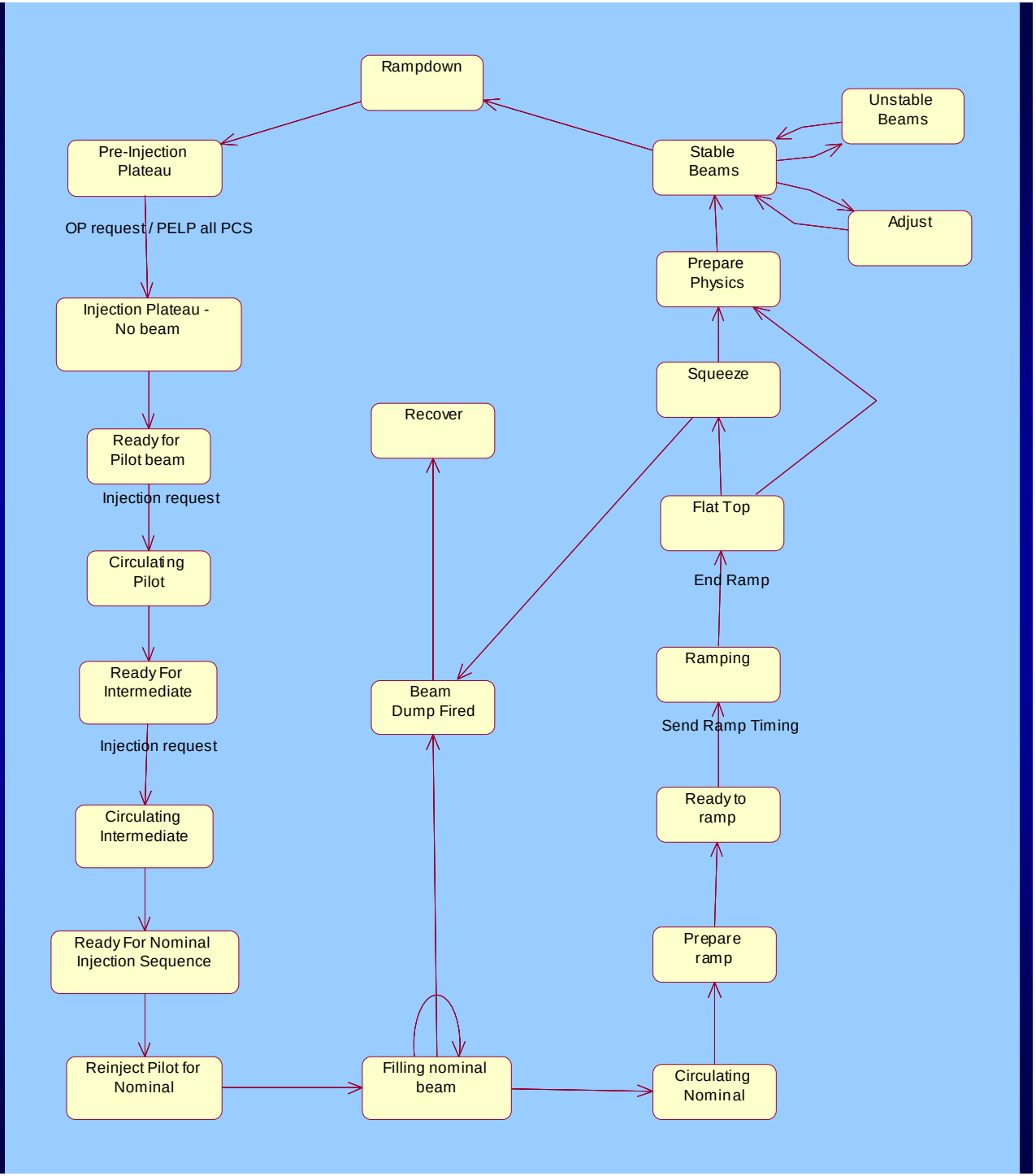
3. Operations

- **SEQUENCER**
  - All beam related modes of operation and covering all operational scenarios
- **OPTIMISATION TOOLS**
  - Generic: bumps, knobs
  - Specific: luminosity, orbit
- **REAL TIME**
  - Closely coupled to core software
- **SCRIPTING ENVIRONMENT**
  - Rapid Application Development

OPERATIONS

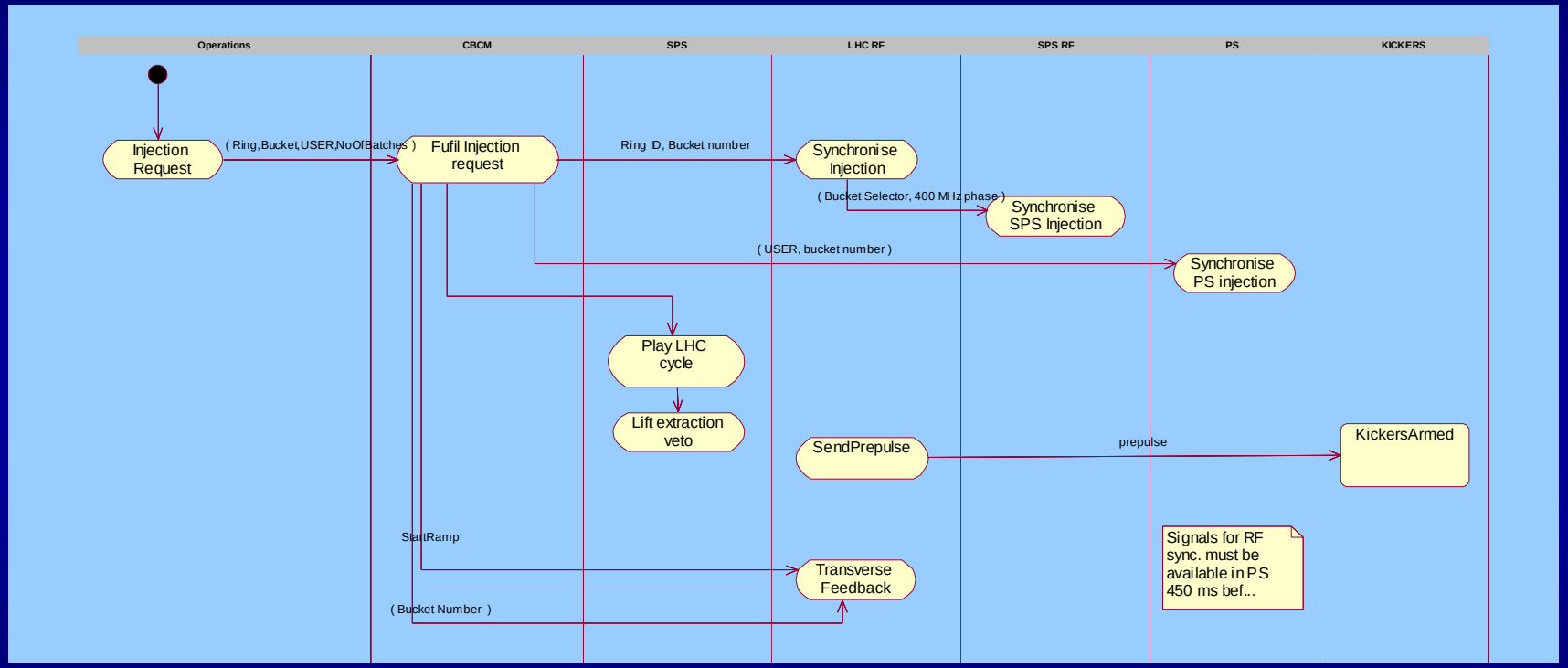
We are going to need a very good sequencer

Analysis in progress



INJECTION

And a very good injection sequencer



OPERATIONS

4. Standard facilities

- **LOGGING: Global logging facilities**
- **ALARMS: Global Alarm System**
- **POST MORTEM : Global Post Mortem system**
- **SETTINGS: A coherent settings management system covering all relevant equipment and beam related settings**
- **TRIM: High level view of beam & accelerator allowing adjustment in terms of appropriate parameters**

4. Standard facilities

- MEASUREMENTS
- FIXED DISPLAYS
- ANALOGUE ACQUISITION
- STANDARD TIMING
- STANDARD DATABASE
- STANDARD EQUIPMENT ACCESS

Settings

Clearly settings management etc. is going to be critical

- **Coherent Parameter Space**
  - **Momentum, tune, chromaticity**
  - **Magnet strengths**
  - **Multipoles b3-model, b3-rm, b3-sg, b3-ramp**
  - **Power converter currents inc. nested triplets**
  - **Knobs**
  - **Kickers, collimators, TDI…**
- **With appropriate settings at all levels**

- **Settings generation/trim etc.**

STANDARD FACILITIES

Settings in use

- **Play injection plateau**
  - Subset or all PCs
  - Correctors for energy stability
  - Multipole error compensation
- **Prepare ramp**
  - Incorporation
  - Calculation of snapback depth, adjustment of ramp functions
- **Ramp**
  - Snapback, Stop
- **Squeeze**
  - Q,Q' orbit, stop, adjust, continue
- **Feed-forward**
  - From feedback systems
  - From reference magnet systems
- **Spectrometer compensation**
- **Crossing angle**
- **Separation bumps**
- **Tune, chromaticity, dispersion, momentum**

STANDARD FACILITIES

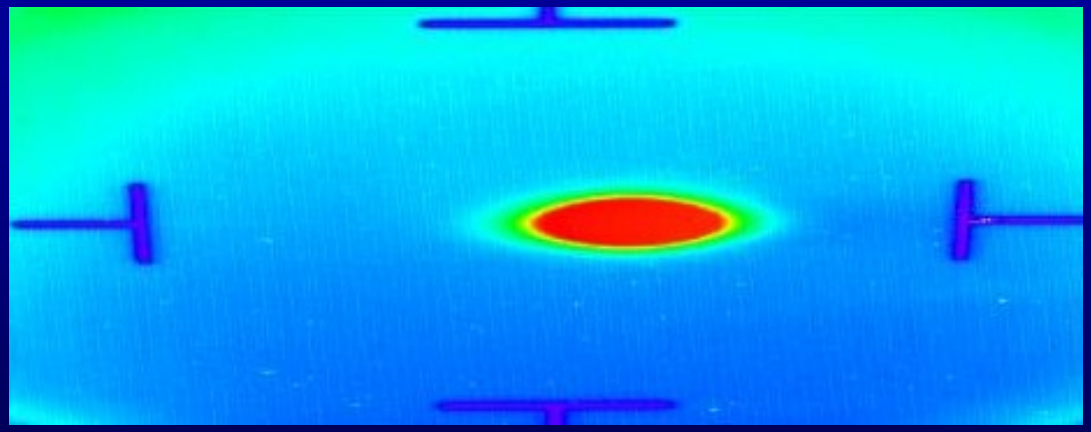
Fixed displays

STANDARD FACILITIES

- **On-line monitoring of the state and tolerances of everything will be required, dynamic, configurable, mode dependent. Any exceptions will raise alarm and possibly throw the beam or power permit Feeds of this stuff to remote sites, video channels, web...**
- **Screen capture, replay, mode dependencies**
  - **Monitoring and diagnostic of interlock systems**
  - **Display of injection screens: 2-d images, profiles, beam sizes & positions, x,x', at injection point**
  - **Fixed displays of transfer lines: bunch currents, beam sizes, beam loses, beam position, screens**
  - **BLMs: arcs, collimators**
  - **BCT total, bunch by bunch, possibly showing limits outside which beam-beam becomes a problem,**
  - **QPS & Energy extraction system**
  - **Cryogenics summary status, magnet temperature**
  - **Power converter status,**
  - **Vacuum**
  - **Radiation monitors**
  - **TDI, TCDD, TCDQ**
  - **Collimator positions**
  - **Global orbit plus crossing angles, beam separation, transverse position along a batch, turn by turn etc. et**
  - Monitoring of control system components: **front-ends, gateway, front end controllers etc..**
  - **Head tail display**
  - **RF: Qs - longitudinal PU , Mountain range turn by turn, unit status**
  - **Monitor feedback loops.**
  - **Experiments: status, luminosity, backgrounds, radiation...**

MEASUREMENTS

- Acquisition
- Concentration
- Archival
- Data format
- Analysis tools



STANDARD FACILITIES

STANDARD FACILITIES

ALARMS

A COHERENT UNIVERSAL ALARM SYSTEM IS AN ABSOLUTE NECESSITY

We don’t want to have to wander off to a corner of the control room to see if x subsystem has had a problem.

STANDARD OPERATIONAL FACILITIES

- Standard Console manager
- (Standard back-end O/S)
- Standard error handling facilities
- Standard network diagnostics
- Standard Front-end diagnostics and reboot facilities
- Standard alarm system interface
- Standard Electronic Logbook
- Standard Web based documentation
- Standard database utilities
- Standard screen capture & print utilities
- Standard tools and software components: data visualisation, data editing, fixed displays
- Standard support applications such as phonebook etc.

Controls Monitoring & reboot

- **Timing**
  - **Slow: diagnostics, tests**
  - **CBCM: what's it up to?**
- **Status**
  - **Front-ends/Field buses**
  - **Gateways**
  - **Network**
  - **Servers**
  - **Databases**
  - **…**

5. INTERFACES

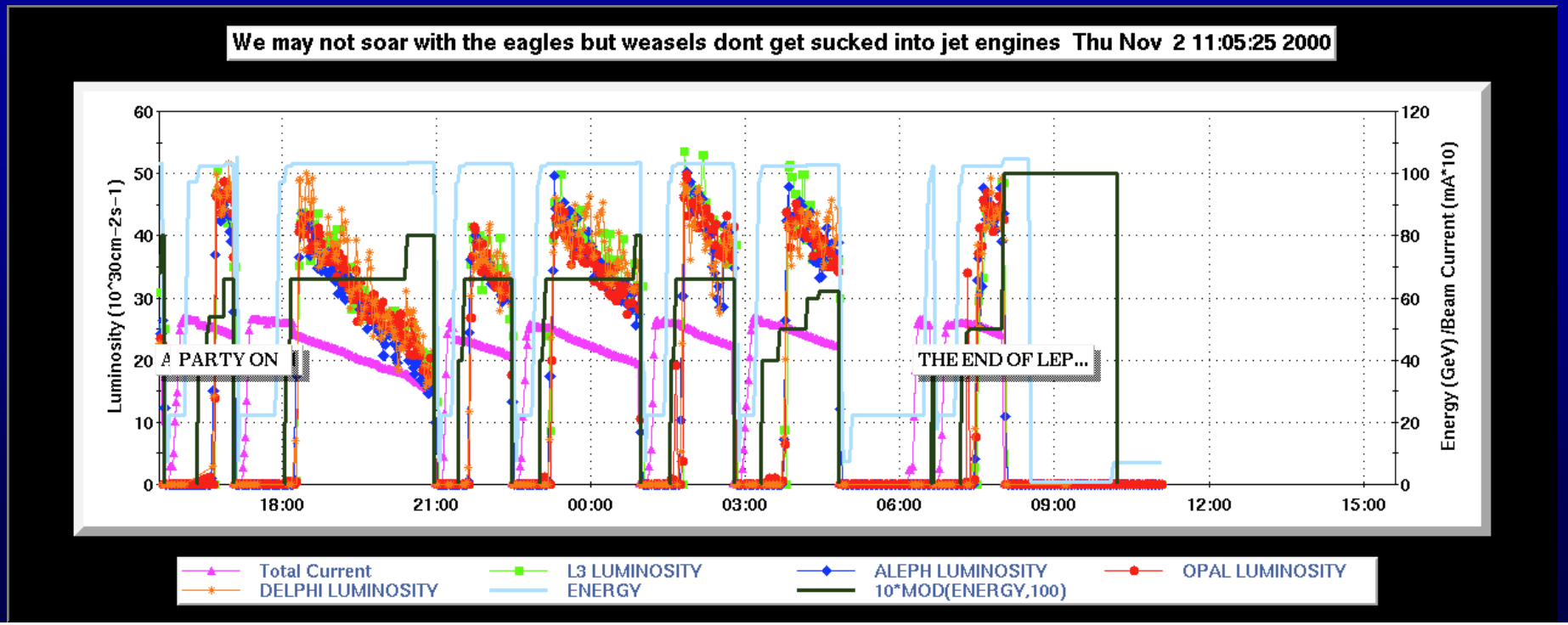
- Off-line/On-line machine model
- Reference Magnet System
- Experiments
- Vacuum
- Cryogenics
- Cryostat Instrumentation
- Interlocks
- QPS
- Access
- Radiation monitors (RAMSES)

LOGGING,
POST-MORTEM,
FIXED DISPLAY,
DATA EXCHANGE

- MACHINE PROTECTION

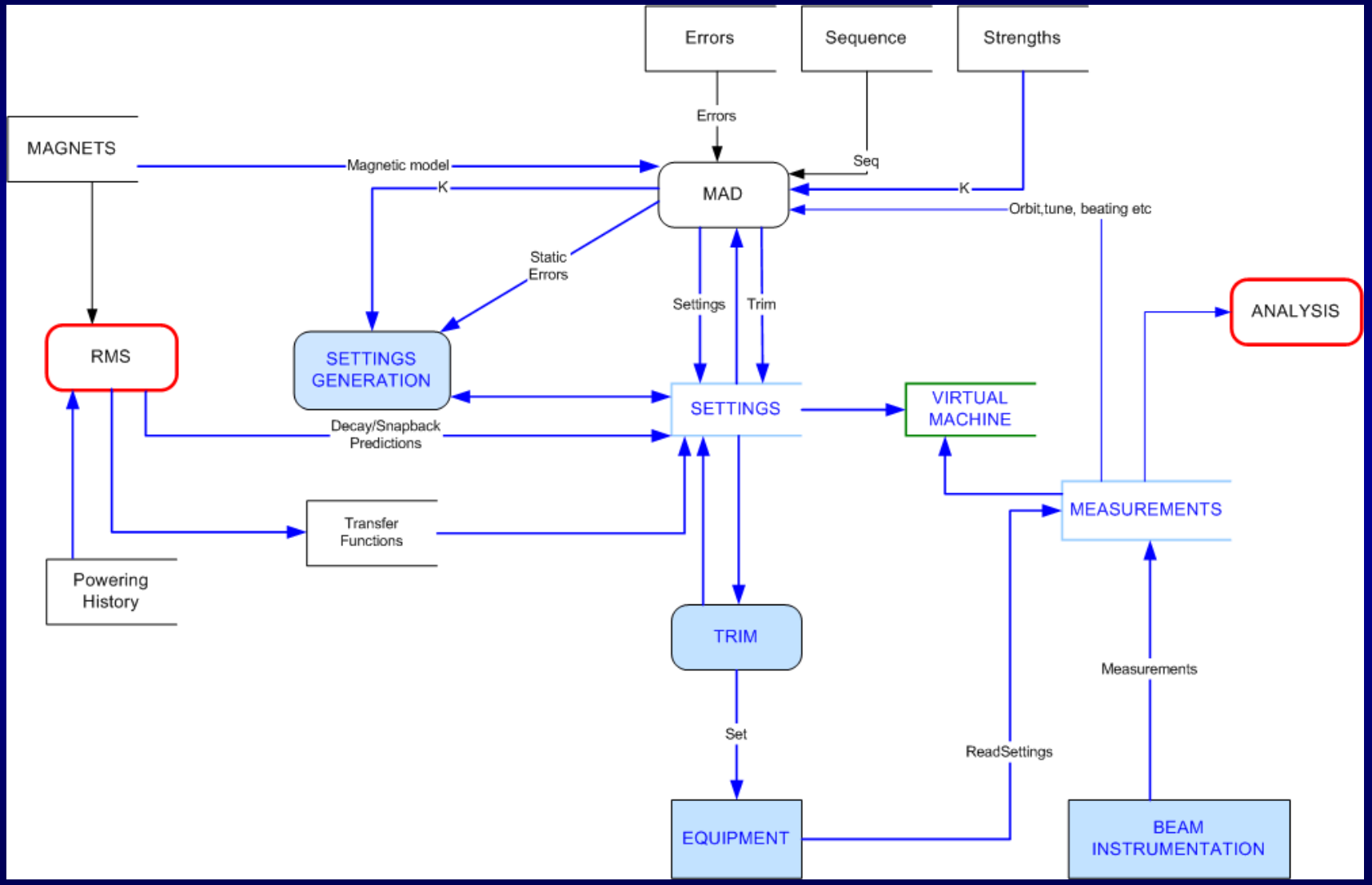
INTERFACE WITH EXPERIMENTS

- Data exchange
- Logging
- Fixed Display



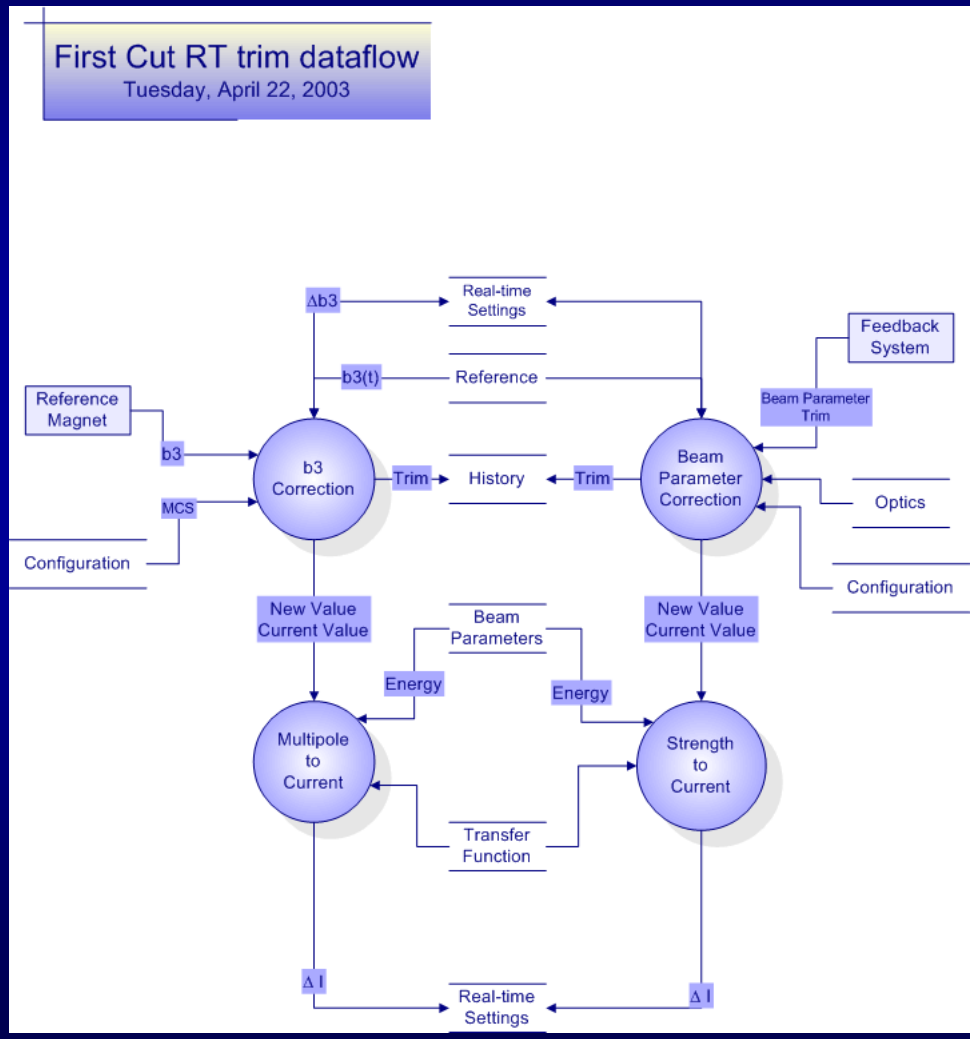
MACHINE MODEL & RMS

INTERFACES



Interaction with real-time

- **RT use of:**
  - Transfer functions
  - B2I model
  - History
  - Configuration data
  - Optics
- **Concurrent trims or not**
  - Lock-out



Other issues

- Security
- Remote access
  - Piquets
  - LHC@FNAL
- Safe Settings
- Software development environment
  - Rigorous version control
  - Test environment
- Support

Milestones

- **Hardware Commissioning**
  - Getting to grips with power converters
  - PIC, QPS, EE, Cryogenics, Cryostat instrumentation
  - Post Mortem, Logging, Alarms, Fixed displays
- **Sector Test – end 2006**
  - Key BI systems
  - Some key equipment
  - Some key facilities and software

Extremely useful staging point

- **Commissioning - 2007**
  - Some stuff can wait – but not a lot.

Conclusion

STANDARD SOLUTIONS ARE THE ONLY WAY WE ARE GOING TO GET ANYWHERE NEAR THIS LOT

And there are some other issues that need addressing

LHC software analysis

LHC sector test