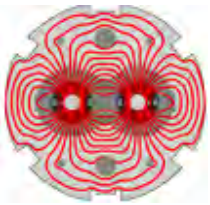
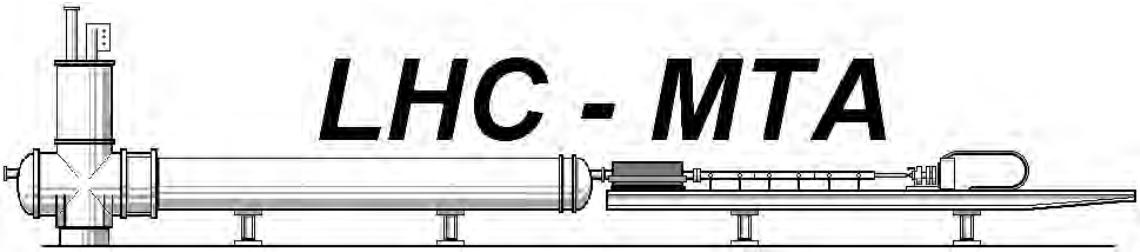


Data Analysis Project for the LHC Series Magnets Field Quality Measurements

Laurent Deniau, CERN-LHC/MTA

October 2001

Laurent.Deniau@cern.ch



Magnet Tests and Results

Tests in charge

- ☞ Tests of Dipoles ($\approx$ 1200) at CERN
  warm and cold conditions.
- ☞ Tests of SSS ($\approx$ 500) at CERN
  warm and cold conditions.
- ☞ Tests of Correctors ($\approx$ 8000) in industry
  warm and cold conditions.
- ☞ Tests of Correctors ($\approx$ 500) at CERN
  warm and cold conditions.

Analysis results & LHC Database (Digested data)

- ☞ Summary of magnet tests results will be provided in the electonic document Magnet test traveller (pdf).
- ☞ Summary of magnet tests digested data will be provided in the Reference view available from the Manufacturing and Test Folders (MTF).
- ☞ Magnet tests digested data are provided through Reference tables and committed after approbation to the LHC database.

Overview of the Data Analysis Project

Field Quality Tests Requirements

☞ Dipoles and Quadrupoles
- $\Longrightarrow \approx 1\,200$ Dipoles + 500 SSS.
- $\Longrightarrow \approx 1\,000$ measurements per Dipole or SSS.
- $\Longrightarrow \approx 20\,000\,000$ magnetic measurements.
- $\Longrightarrow >$ 200 GB Database.

☞ Correctors
- $\Longrightarrow \approx 8\,000$ magnets.
- $\Longrightarrow$ Number of measurements is negligeable.
- $\Longrightarrow$ Many variety of correctors.

Data Analysis Project

☞ Analysis Cluster
- $\Longrightarrow$ 5 PCs Twin PIII 600 MHz running Linux.
- $\Longrightarrow$ WWW Analysis Servers.

☞ Analysis Tools
- $\Longrightarrow$ 15 Modules ($\approx 150\,000$ lines of code).
- $\Longrightarrow$ Analysis on the fly (rate of $\approx 1\,800$ meas./sec).

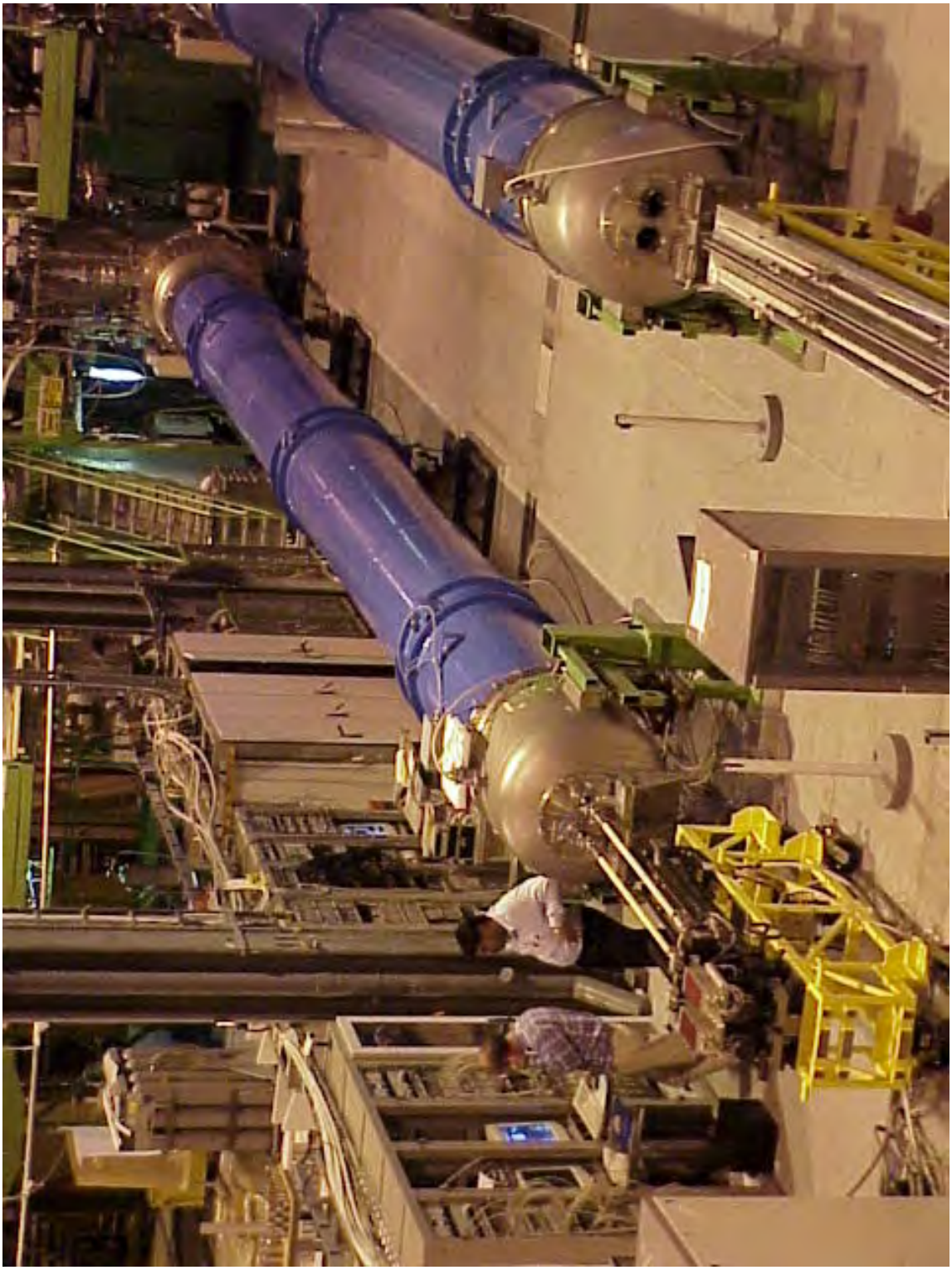
☞ Automatic Analysis
- $\Longrightarrow$ Database rate $\approx$ 80 meas./sec (5 min/magnet).
- $\Longrightarrow <$ 10 min for full magnet field analysis.

☞ Interactive Analysis
- $\Longrightarrow$ Fast, reliable.
- $\Longrightarrow$ Available on the web.

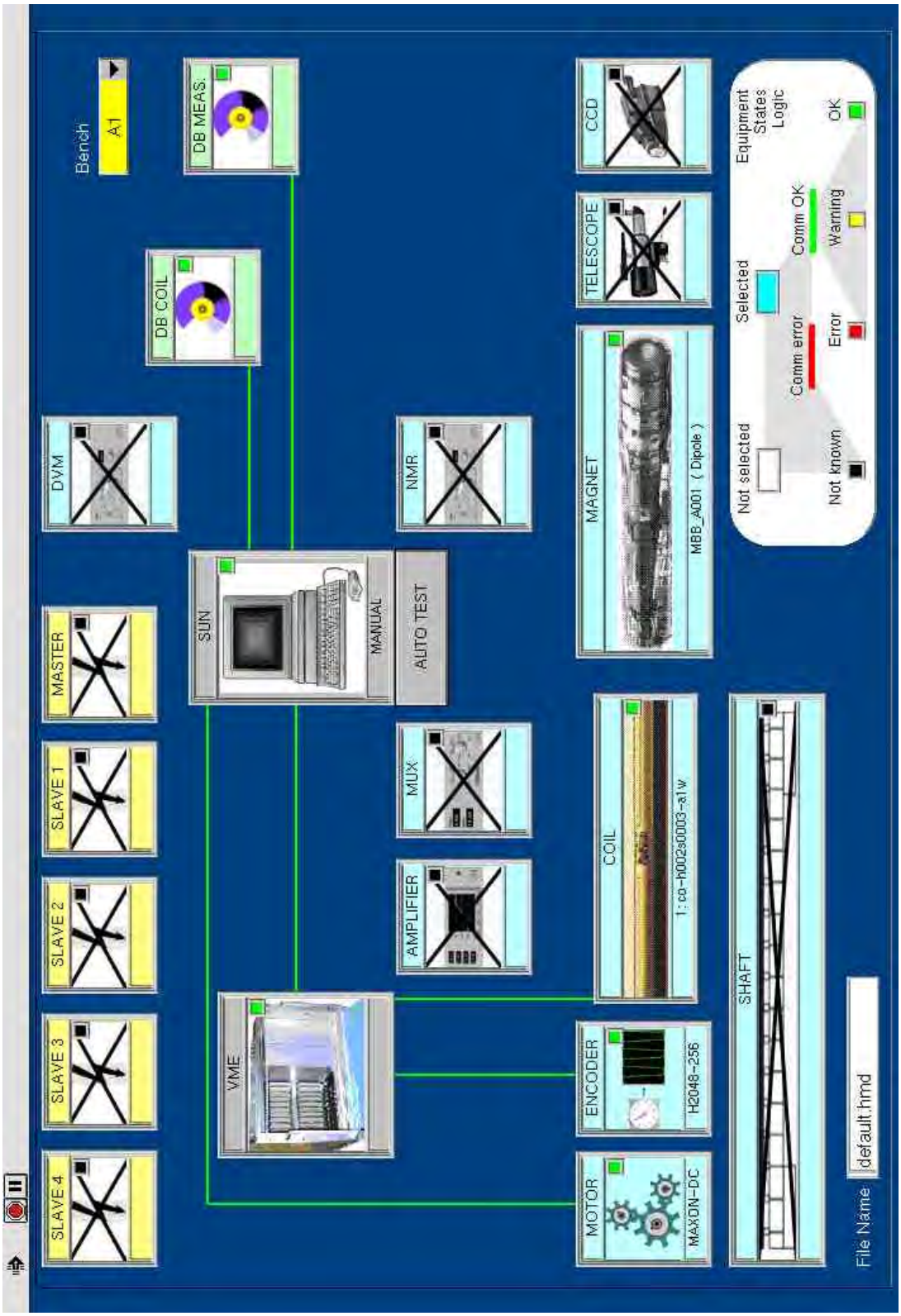
Sites

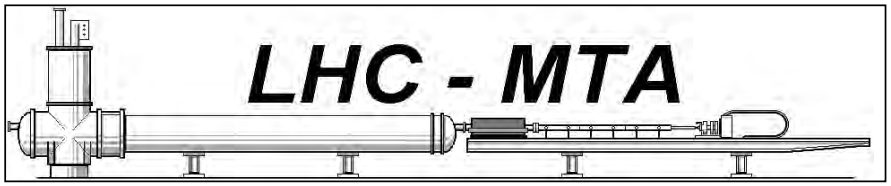

Bloc 4
Short Magnets
Test Site
CAT (India)
WWW support
Industry
Short Magnets
Test Site
SM18
& SMA18
Long Magnets
Test Site
Bld. 35
Database Server
Bld. 30
LHC/MTA
Bld. 513
Analysis Servers

Test Benches and Magnets



Magnetic Measurement Program





Data Flow Chart

@CERN (B4, SM18) & @Industry

MTA | **LHC/EST-ISS**

Magnet Tests Systems

(LabView)

Test Instrumentation Traveller

Test Instrumentation Data

MTA DB

(raw data 0.5TB)

Magnet Test Traveller

Magnet Reference Data

Analysis Tools

(LabView, Excel, C, Web)

LHC DB

(digested data 1GB)

Information Tools

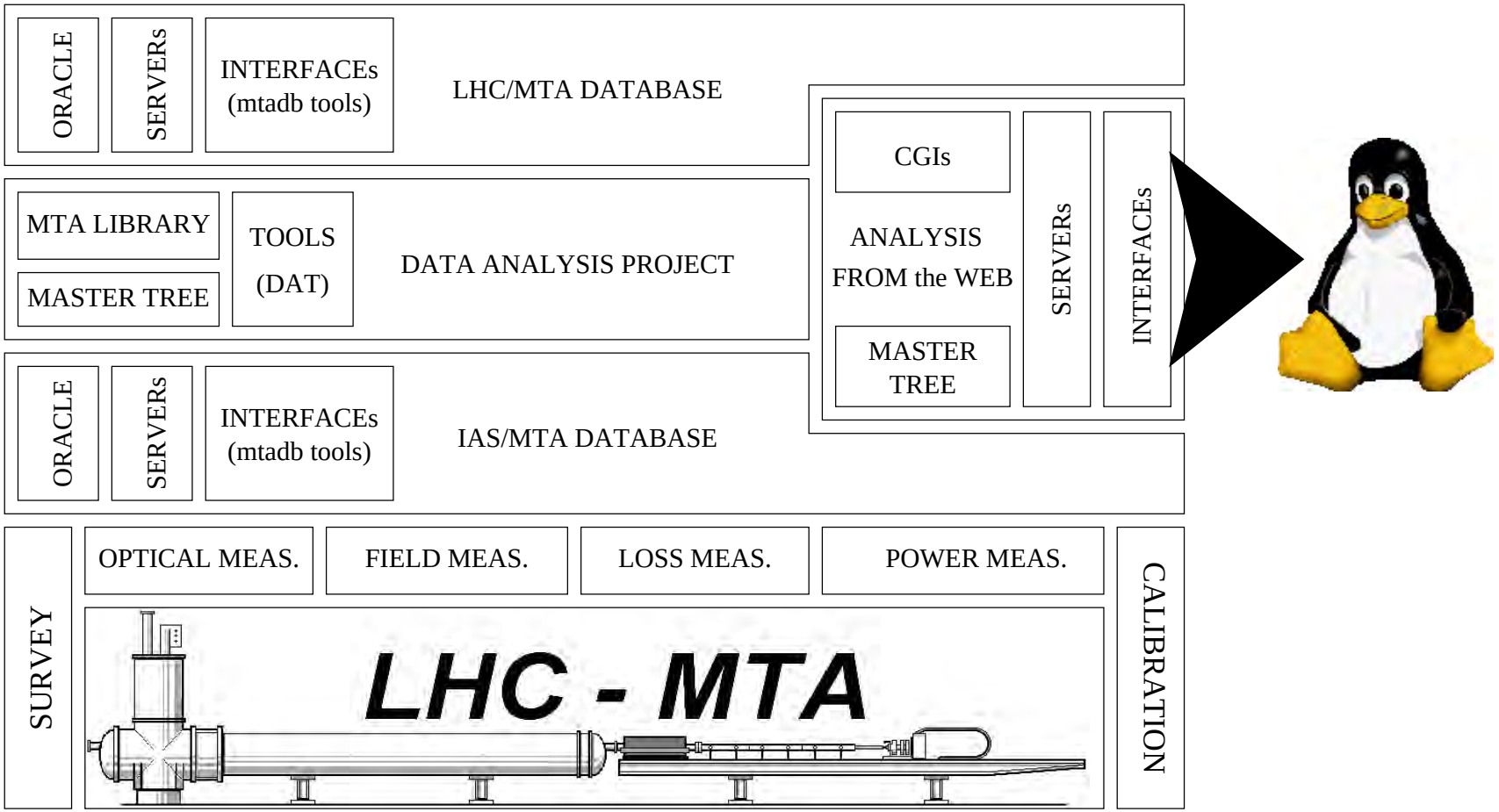
Analysis Tools

← Tests & Measurements → ← Analysis & Data Reduction →

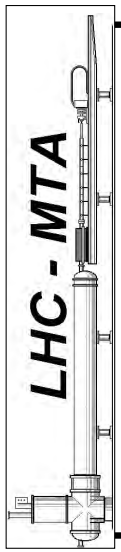
Provider side

Client side

Data Analysis Project



Data Analysis Project



Axis & Optical Measurement Program
- Data Acquisition
- Simple Analysis

Magnetic Measurement Program
- Data Acquisition
- Simple Analysis

MTA DB
- Coil Parameters
- Head Parameters
- Magnetic Measurements
- Optical Measurements

Automatic Calibration
- Head Calibration
- Optical Calibration
- Axis Calibration

Calibration Measurement Analysis
- Coil Calibration
- Head Calibration
- Optical Calibration
- QCD Calibration

Magnetic Measurement Analysis
- Drift Correction
- Volts (angle, time)
- Flux (angle, time)
- Rotation Speed (angle, time)
- Spectrum
- Plots

Local Hamonics Analysis
- Frame Transformations
- Magnetic Center Localisation
- QCD Center Localisation
- Feed Down Correction
- Harmonics Rotation
- Harmonics Normalisation
- Transfert Function
- Plots

LHC DB
- Magnets References Tables
- Magnets Field Quality Reports

Reference Tables Filter

Magnet Hamonics Analysis
- Harmonics Time Averages
- Harmonics Space Integrals
- Field Parameters
- Statistics
- Sorts
- Plots

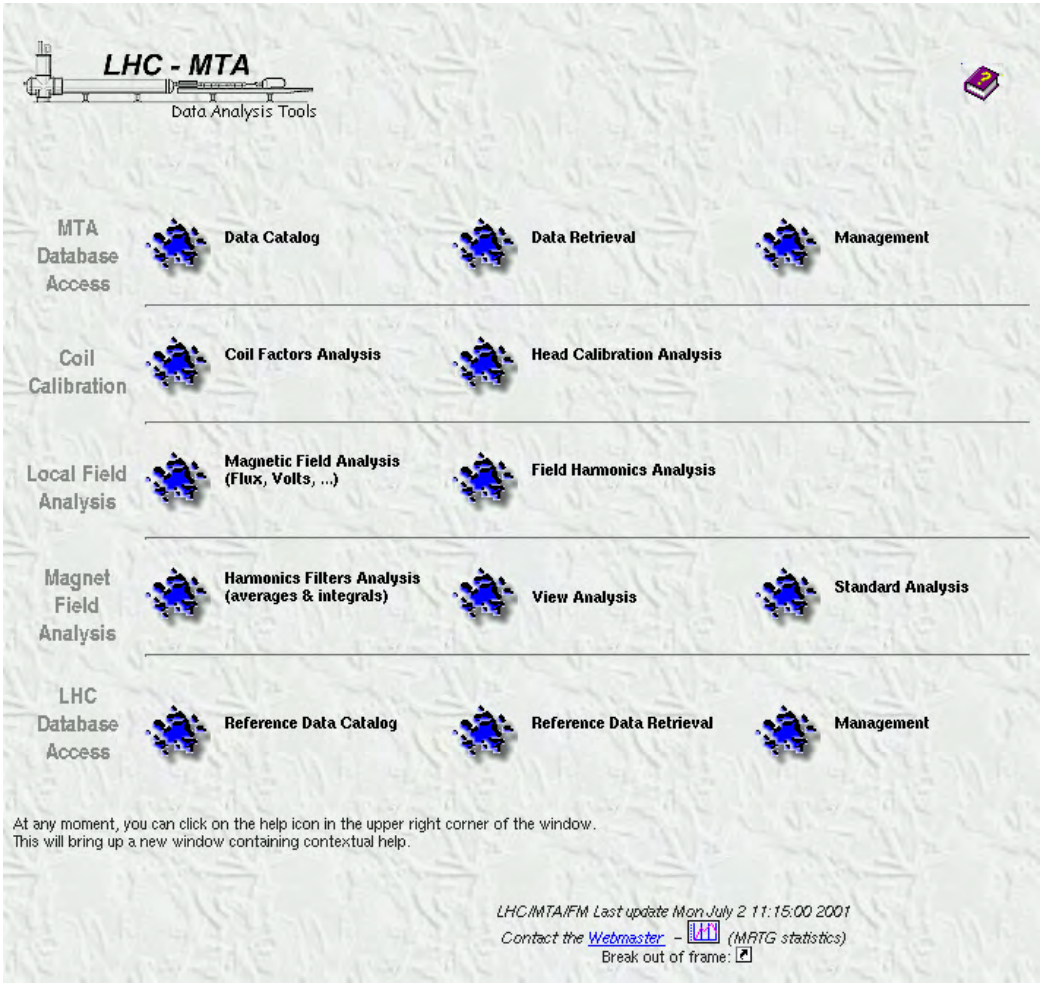
Documentation Generator

Views Generator
- Plots

Cycles Generator
- Load Line
- Ramp Rate
- Magnetization
- LHC Machine Cycle
- Plots

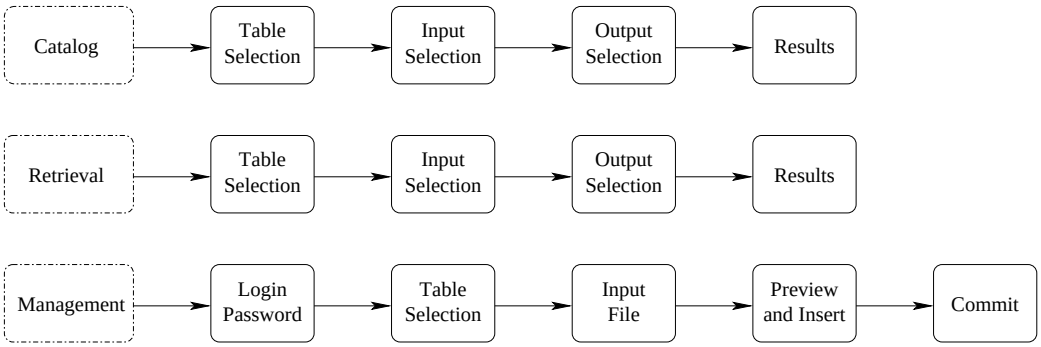
Magnet Standard Analysis
- Load Line
- Ramp Rate
- Magnetization
- LHC Machine Cycle
- Axis Position
- Field Direction
- Plots

DAP Analysis Menus

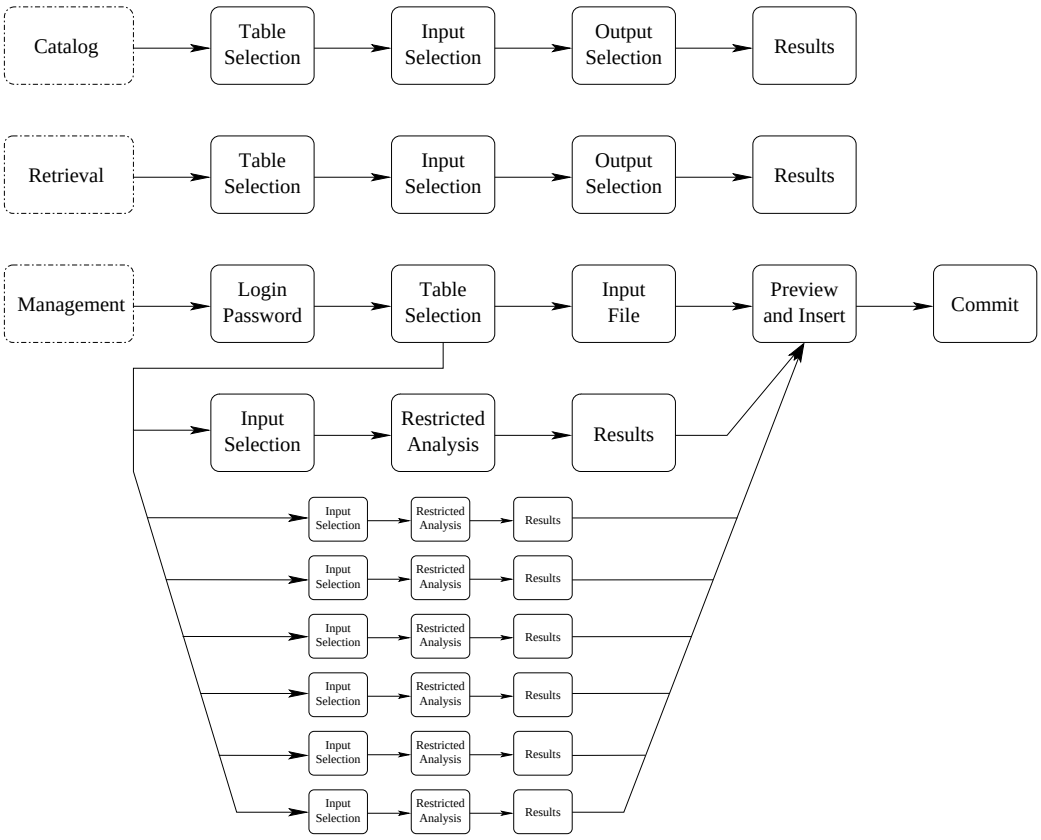


Data Analysis Site Map

MTA Database Access

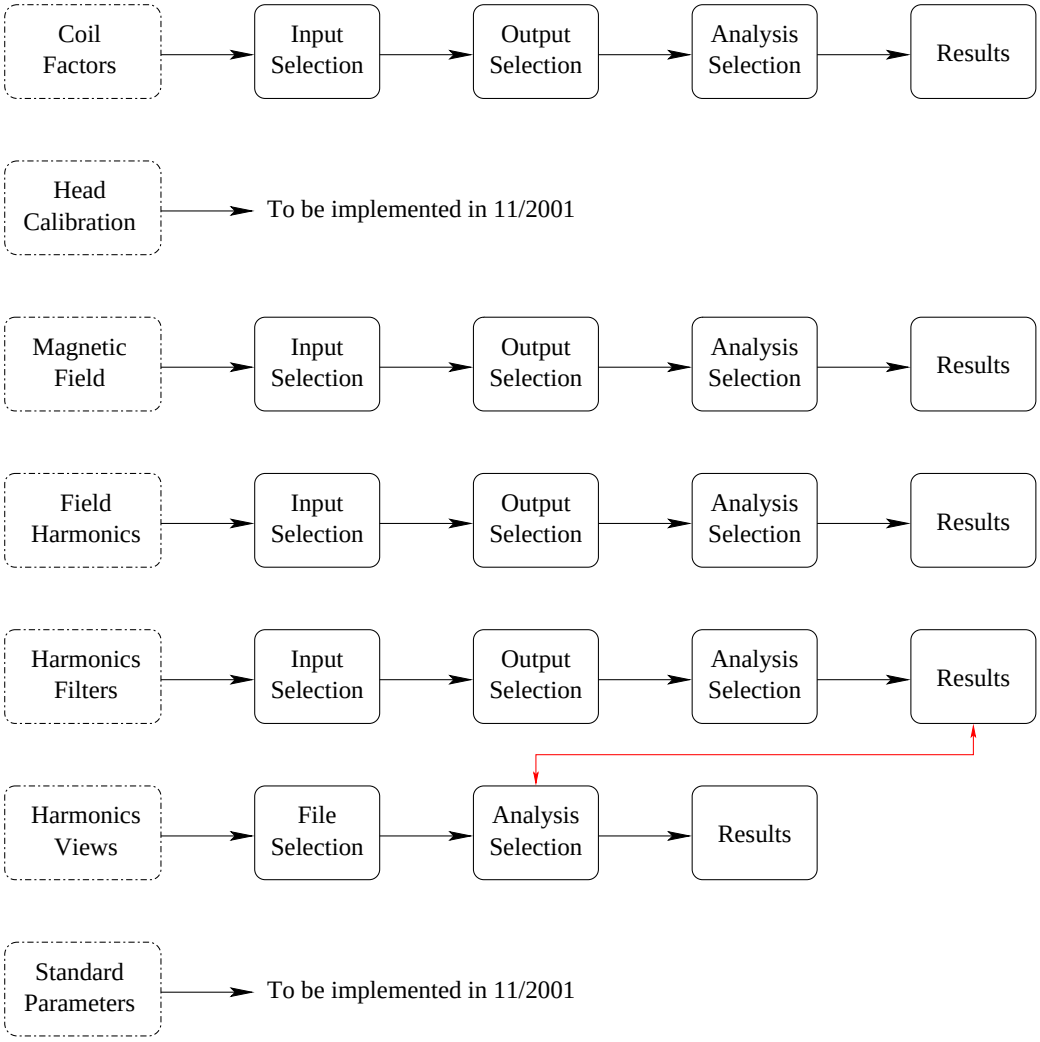


LHC Database Access

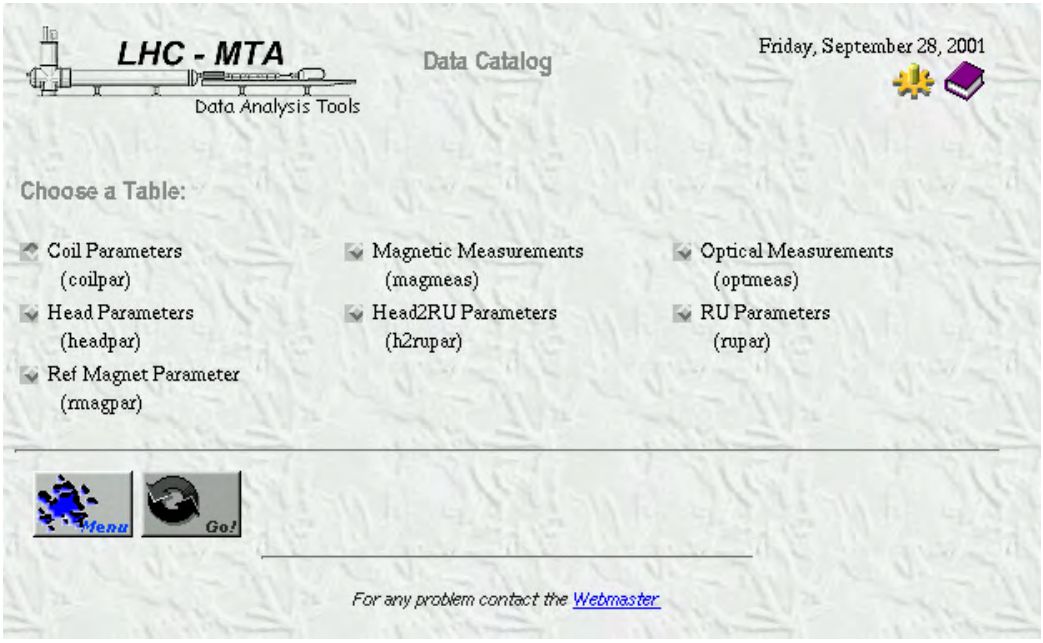


Data Analysis Site Map

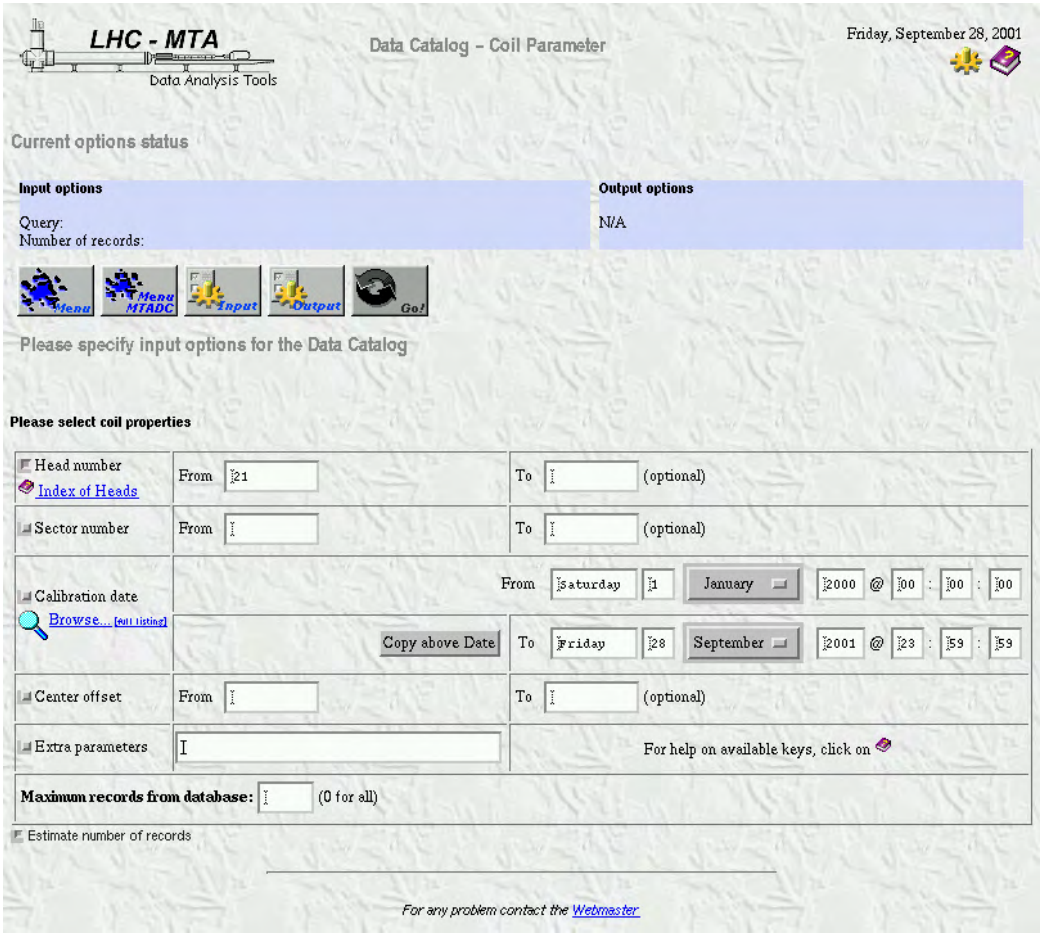
Analysis



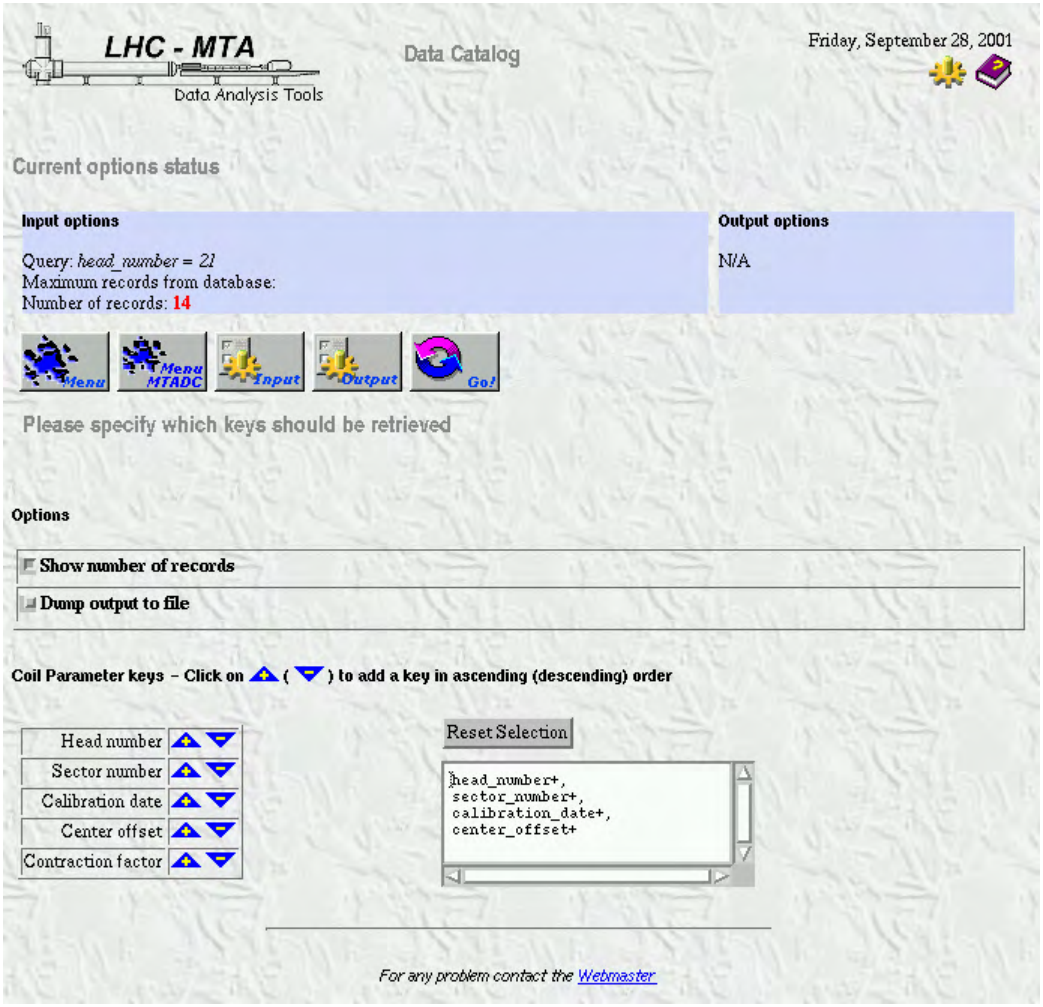
DAP Catalog
Table Selection



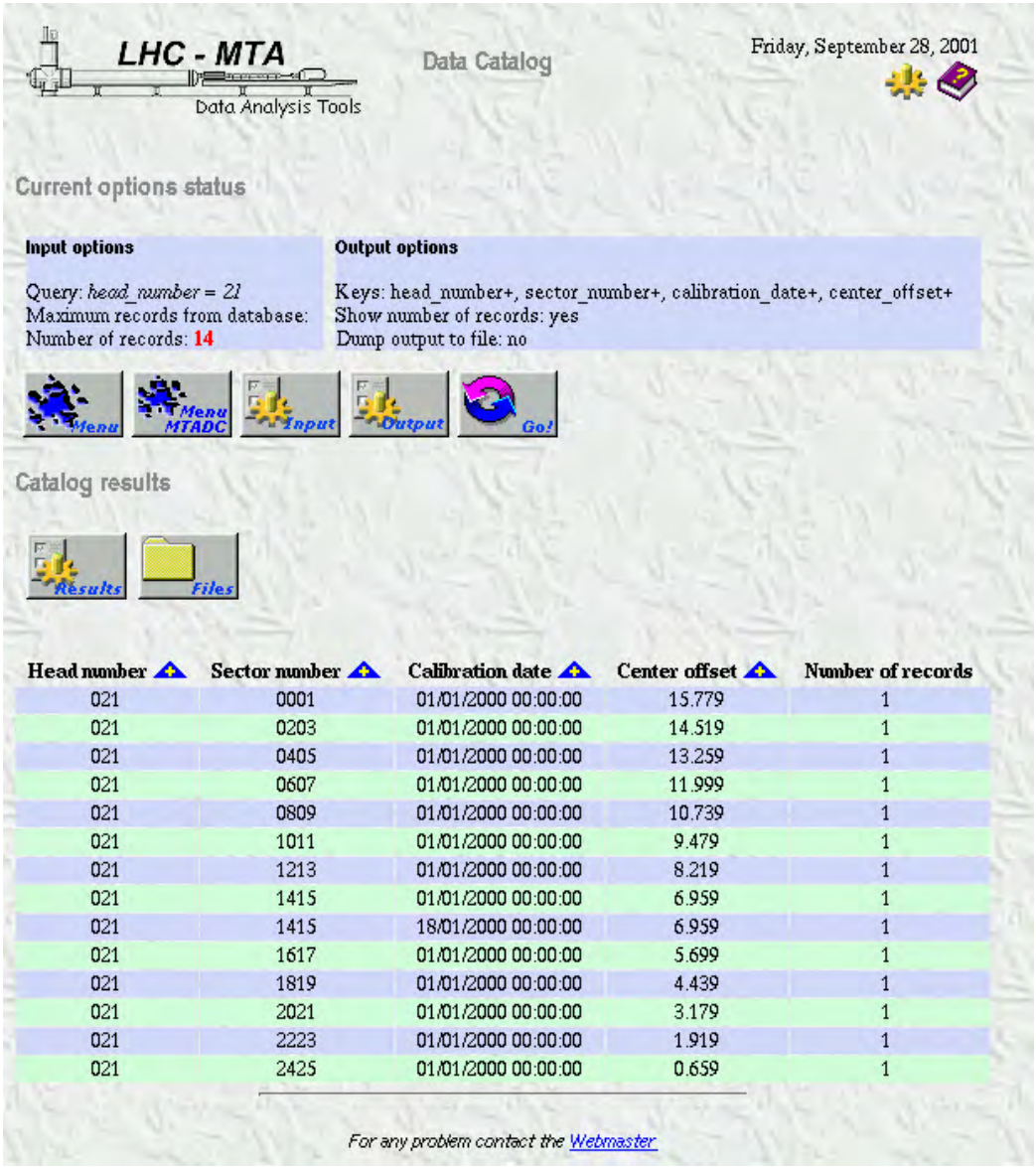
DAP Catalog
Coil Input Query



DAP Catalog
Coil Output Keys Selection



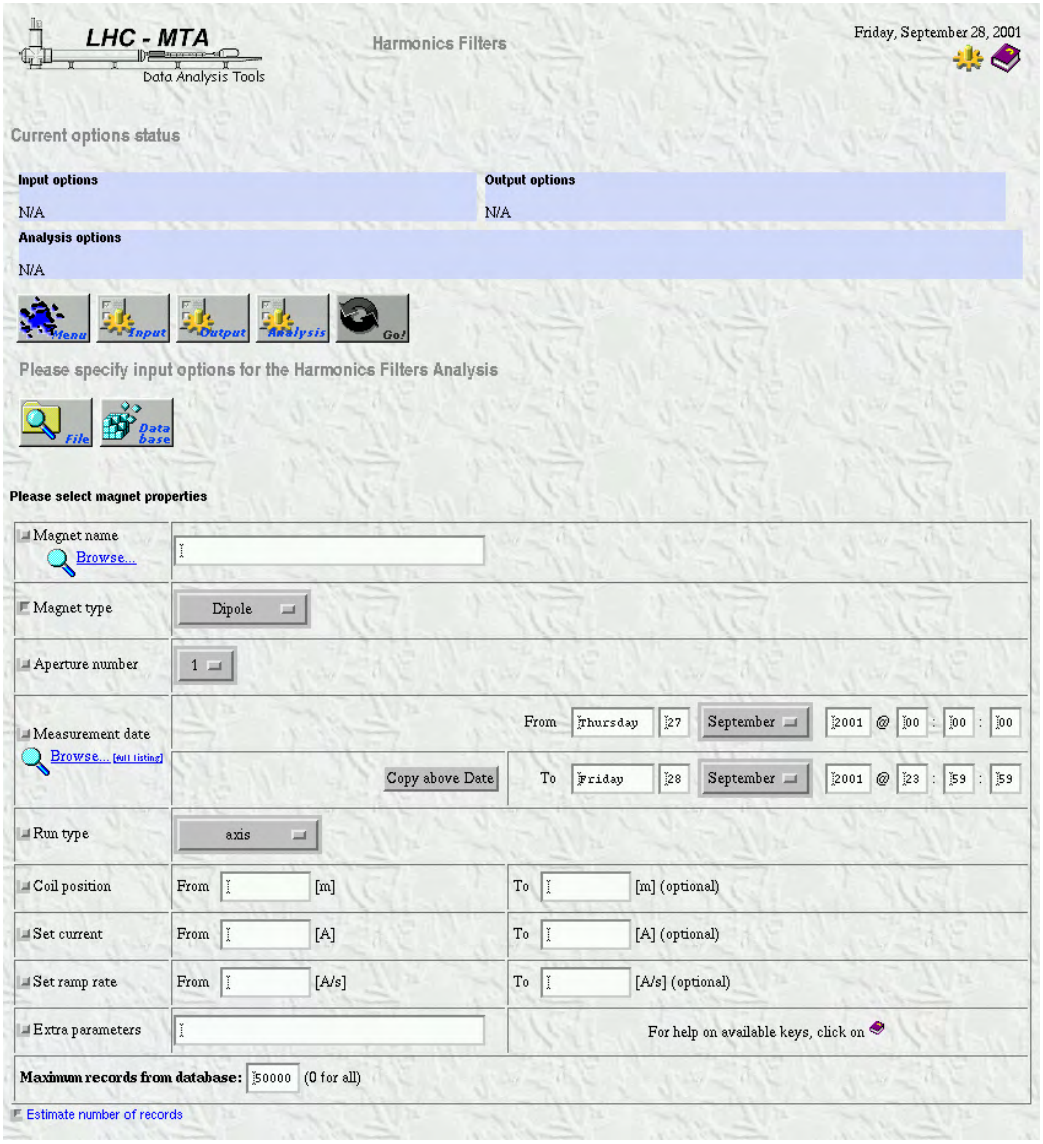
DAP Catalog
Coil Results



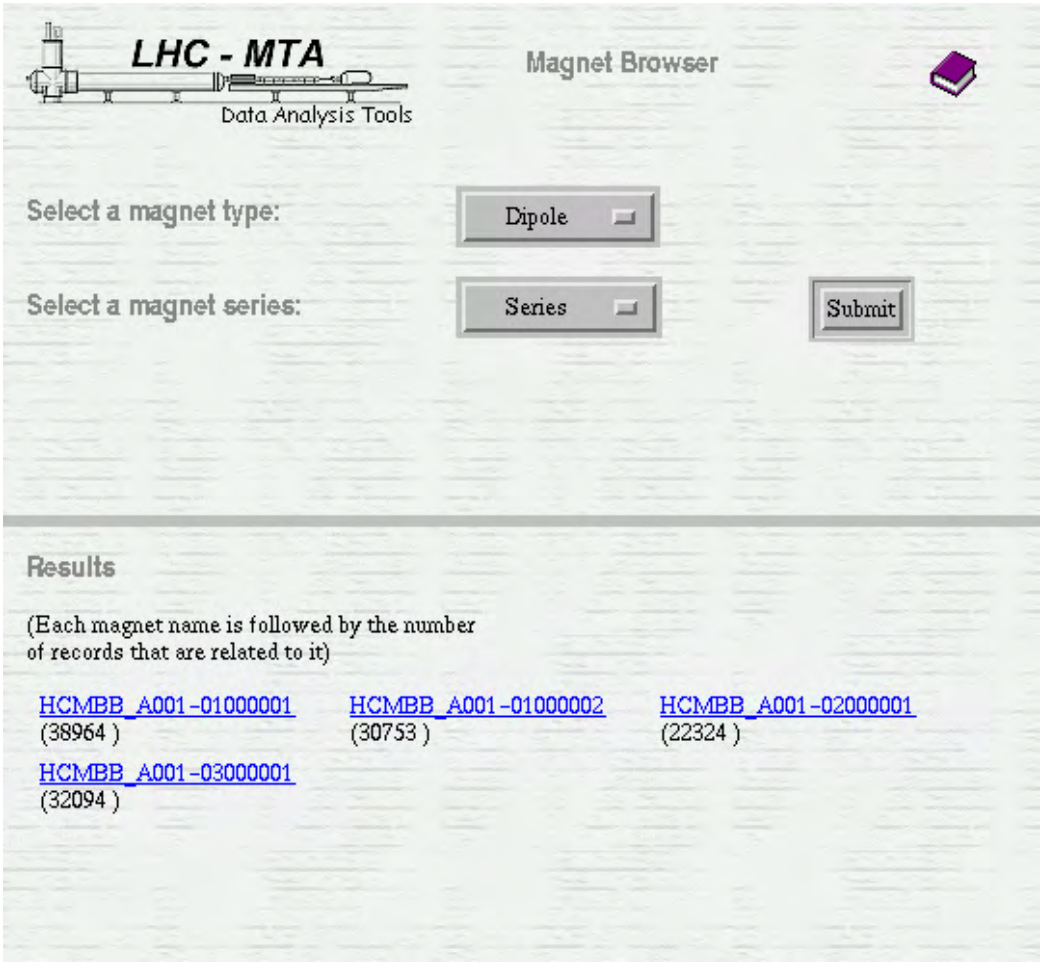
Head number	Sector number	Calibration date	Center offset	Number of records
021	0001	01/01/2000 00:00:00	15.779	1
021	0203	01/01/2000 00:00:00	14.519	1
021	0405	01/01/2000 00:00:00	13.259	1
021	0607	01/01/2000 00:00:00	11.999	1
021	0809	01/01/2000 00:00:00	10.739	1
021	1011	01/01/2000 00:00:00	9.479	1
021	1213	01/01/2000 00:00:00	8.219	1
021	1415	01/01/2000 00:00:00	6.959	1
021	1415	18/01/2000 00:00:00	6.959	1
021	1617	01/01/2000 00:00:00	5.699	1
021	1819	01/01/2000 00:00:00	4.439	1
021	2021	01/01/2000 00:00:00	3.179	1
021	2223	01/01/2000 00:00:00	1.919	1
021	2425	01/01/2000 00:00:00	0.659	1

For any problem contact the Webmaster

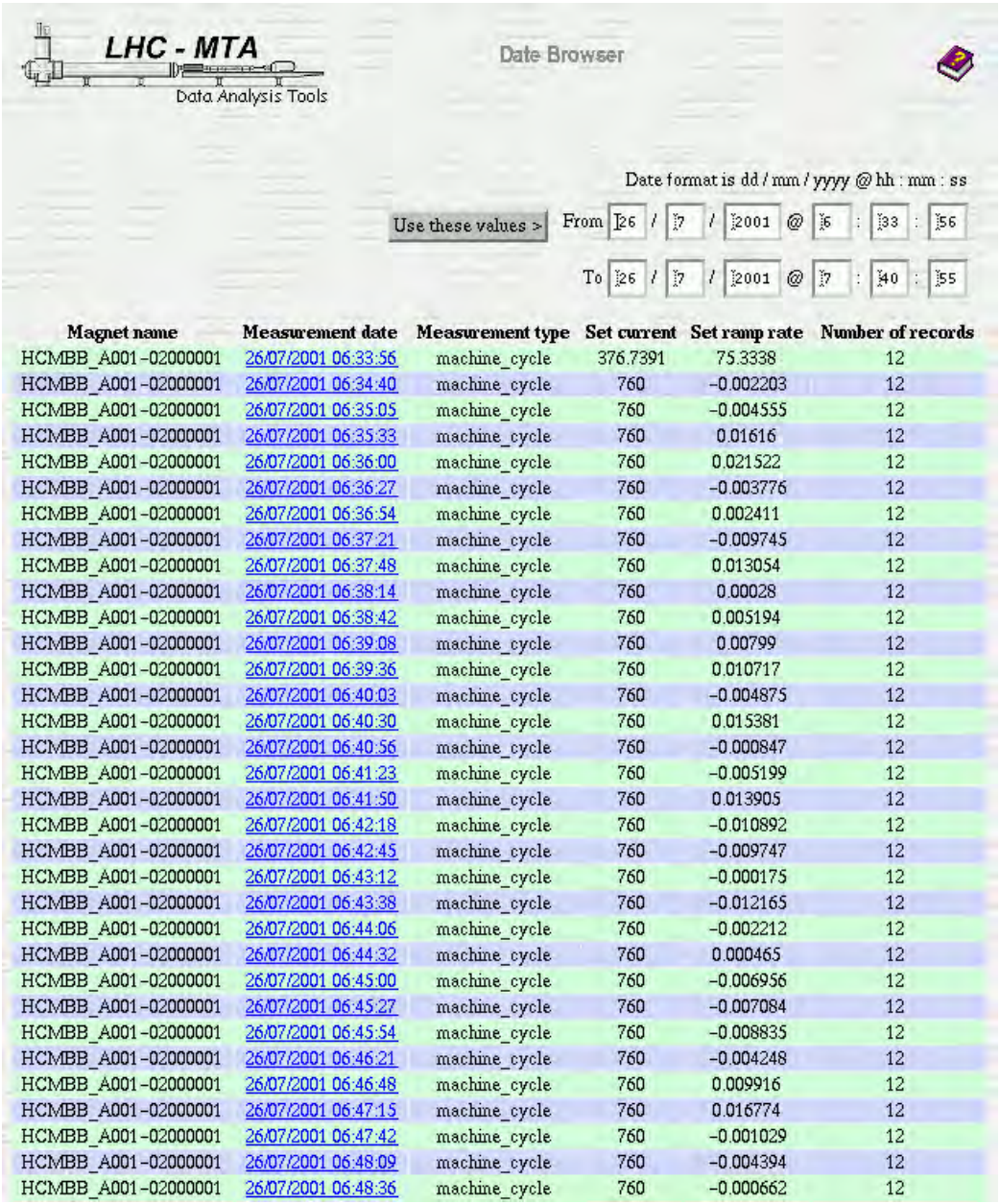
DAP Analysis
Harmonics Input Query



DAP Analysis
Magnet Browser



DAP Analysis
Date Browser



Magnet name	Measurement date	Measurement type	Set current	Set ramp rate	Number of records
HCMBB_A001-02000001	26/07/2001 06:33:56	machine_cycle	376.7391	75.3338	12
HCMBB_A001-02000001	26/07/2001 06:34:40	machine_cycle	760	-0.002203	12
HCMBB_A001-02000001	26/07/2001 06:35:05	machine_cycle	760	-0.004555	12
HCMBB_A001-02000001	26/07/2001 06:35:33	machine_cycle	760	0.01616	12
HCMBB_A001-02000001	26/07/2001 06:36:00	machine_cycle	760	0.021522	12
HCMBB_A001-02000001	26/07/2001 06:36:27	machine_cycle	760	-0.003776	12
HCMBB_A001-02000001	26/07/2001 06:36:54	machine_cycle	760	0.002411	12
HCMBB_A001-02000001	26/07/2001 06:37:21	machine_cycle	760	-0.009745	12
HCMBB_A001-02000001	26/07/2001 06:37:48	machine_cycle	760	0.013054	12
HCMBB_A001-02000001	26/07/2001 06:38:14	machine_cycle	760	0.00028	12
HCMBB_A001-02000001	26/07/2001 06:38:42	machine_cycle	760	0.005194	12
HCMBB_A001-02000001	26/07/2001 06:39:08	machine_cycle	760	0.00799	12
HCMBB_A001-02000001	26/07/2001 06:39:36	machine_cycle	760	0.010717	12
HCMBB_A001-02000001	26/07/2001 06:40:03	machine_cycle	760	-0.004875	12
HCMBB_A001-02000001	26/07/2001 06:40:30	machine_cycle	760	0.015381	12
HCMBB_A001-02000001	26/07/2001 06:40:56	machine_cycle	760	-0.000847	12
HCMBB_A001-02000001	26/07/2001 06:41:23	machine_cycle	760	-0.005199	12
HCMBB_A001-02000001	26/07/2001 06:41:50	machine_cycle	760	0.013905	12
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HCMBB_A001-02000001	26/07/2001 06:42:45	machine_cycle	760	-0.009747	12
HCMBB_A001-02000001	26/07/2001 06:43:12	machine_cycle	760	-0.000175	12
HCMBB_A001-02000001	26/07/2001 06:43:38	machine_cycle	760	-0.012165	12
HCMBB_A001-02000001	26/07/2001 06:44:06	machine_cycle	760	-0.002212	12
HCMBB_A001-02000001	26/07/2001 06:44:32	machine_cycle	760	0.000465	12
HCMBB_A001-02000001	26/07/2001 06:45:00	machine_cycle	760	-0.006956	12
HCMBB_A001-02000001	26/07/2001 06:45:27	machine_cycle	760	-0.007084	12
HCMBB_A001-02000001	26/07/2001 06:45:54	machine_cycle	760	-0.008835	12
HCMBB_A001-02000001	26/07/2001 06:46:21	machine_cycle	760	-0.004248	12
HCMBB_A001-02000001	26/07/2001 06:46:48	machine_cycle	760	0.009916	12
HCMBB_A001-02000001	26/07/2001 06:47:15	machine_cycle	760	0.016774	12
HCMBB_A001-02000001	26/07/2001 06:47:42	machine_cycle	760	-0.001029	12
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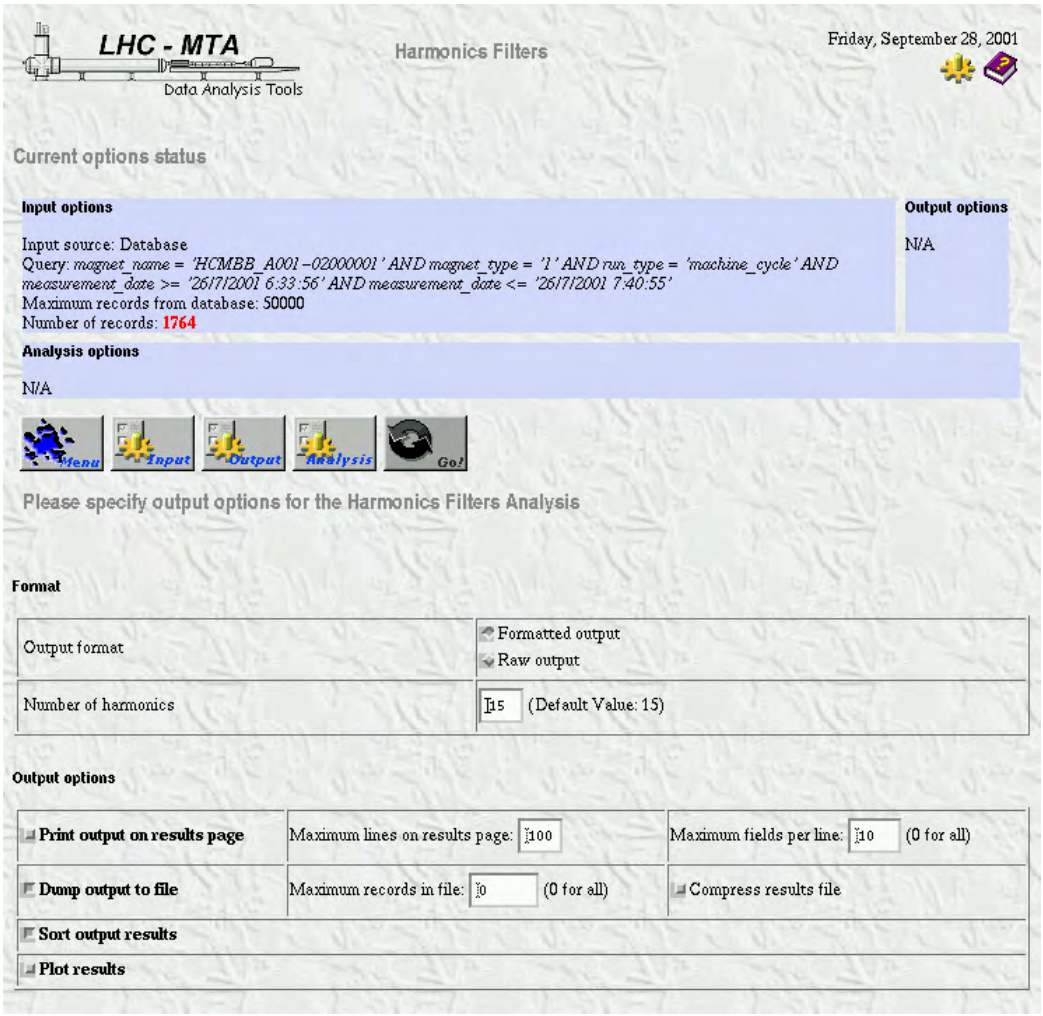
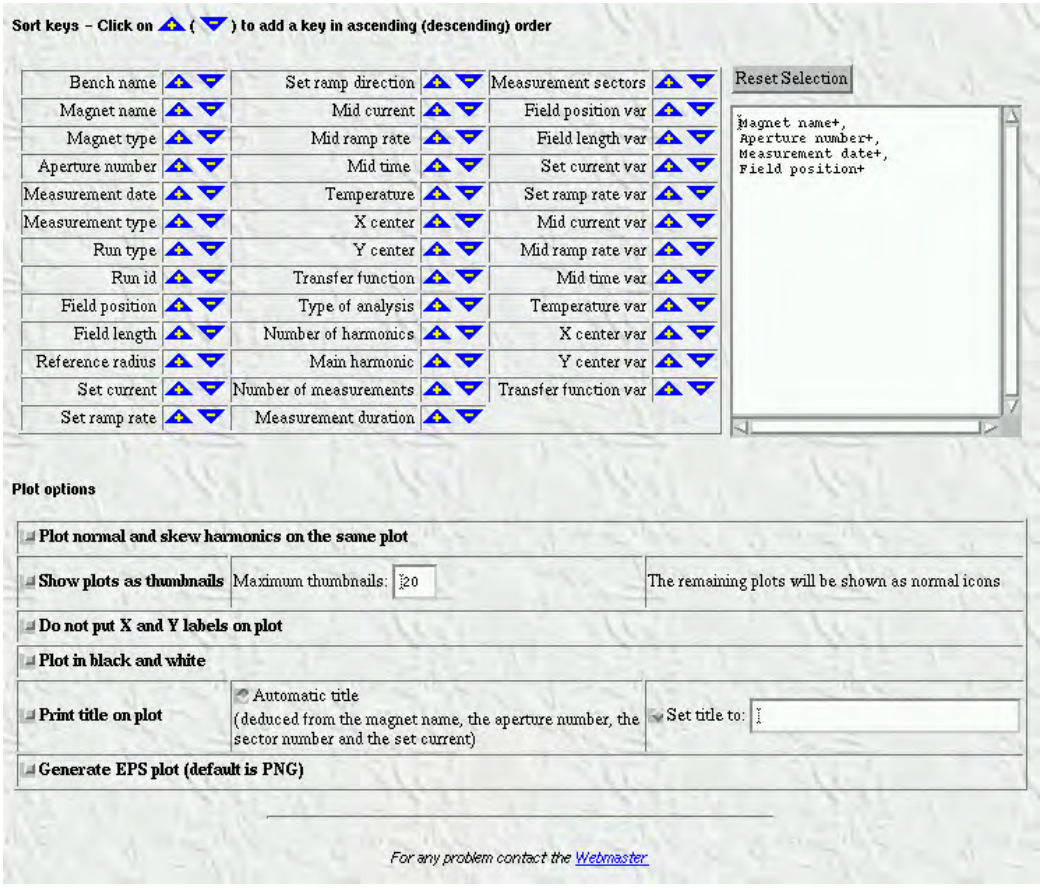
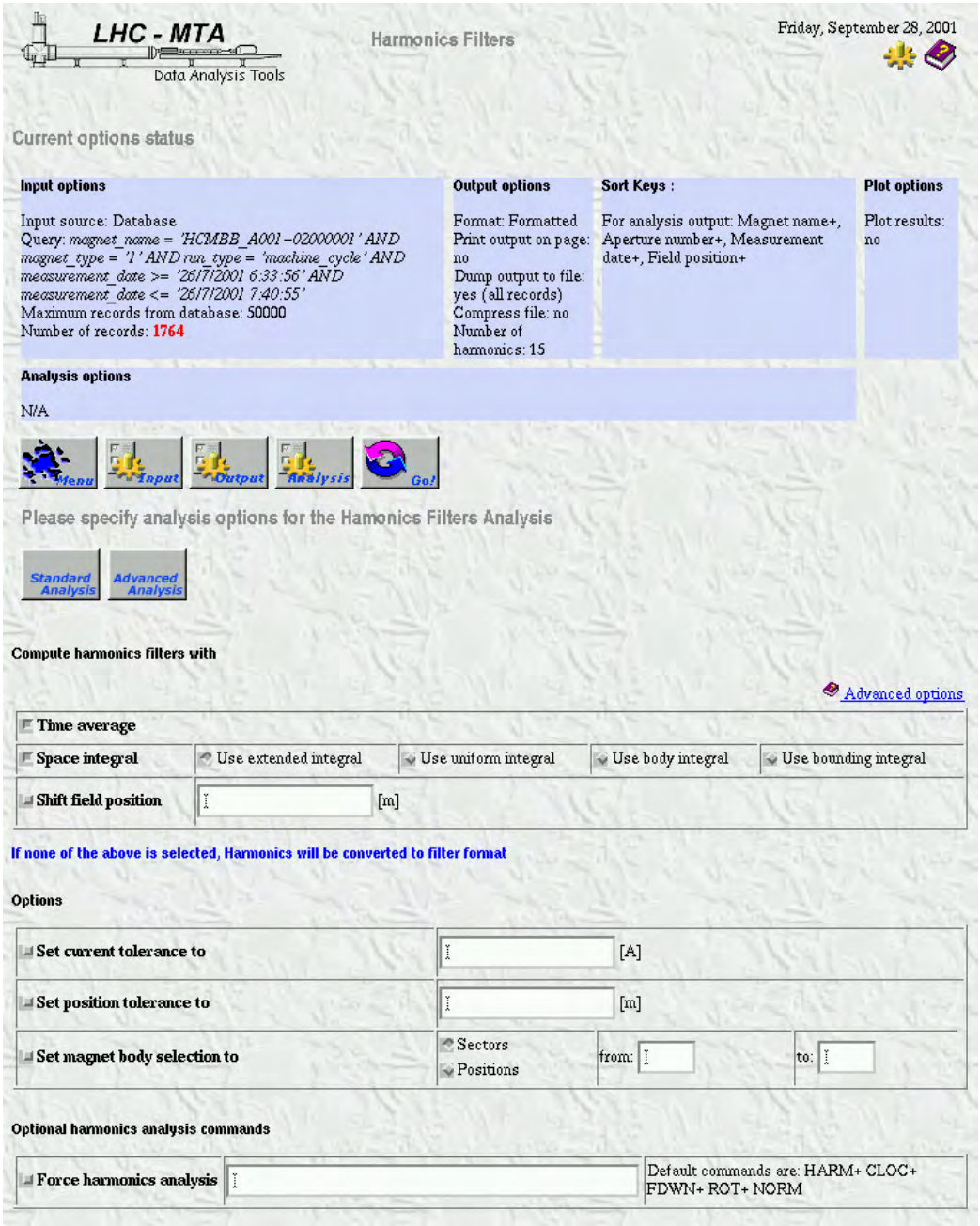
DAP Analysis
Harmonics Output Selection

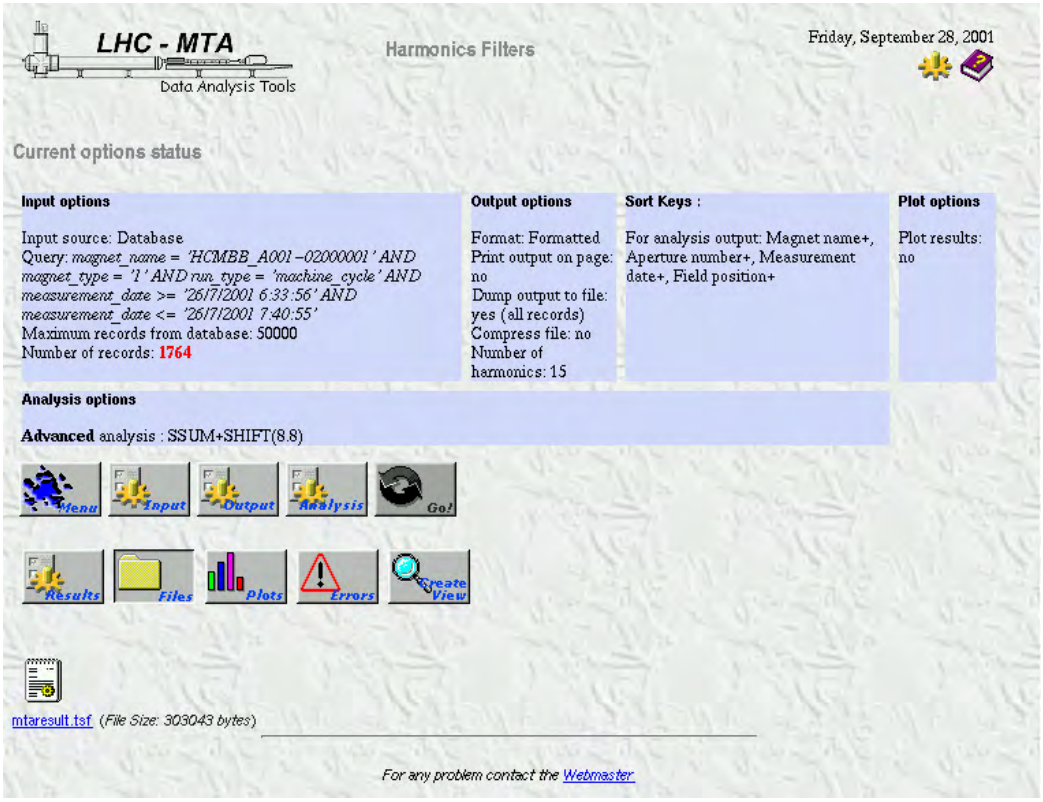



Sort keys - Click on ( ) to add a key in ascending (descending) order
Bench name
Magnet name
Magnet type
Aperture number
Measurement date
Measurement type
Run type
Run id
Field position
Field length
Reference radius
Set current
Set ramp rate
Set ramp direction
Mid current
Mid ramp rate
Mid time
Temperature
X center
Y center
Transfer function
Type of analysis
Number of harmonics
Main harmonic
Number of measurements
Measurement duration
Measurement sectors
Field position var
Field length var
Set current var
Set ramp rate var
Mid current var
Mid ramp rate var
Mid time var
Temperature var
X center var
Y center var
Transfer function var
Reset Selection
Magnet name+,
Aperture number+,
Measurement date+,
Field position+
Plot options
Plot normal and skew harmonics on the same plot
Show plots as thumbnails
Maximum thumbnails: 20
The remaining plots will be shown as normal icons
Do not put X and Y labels on plot
Plot in black and white
Print title on plot
Automatic title
(deduced from the magnet name, the aperture number, the sector number and the set current)
Set title to:
Generate EPS plot (default is PNG)
For any problem contact the Webmaster

DAP Analysis
Harmonics Analysis Selection



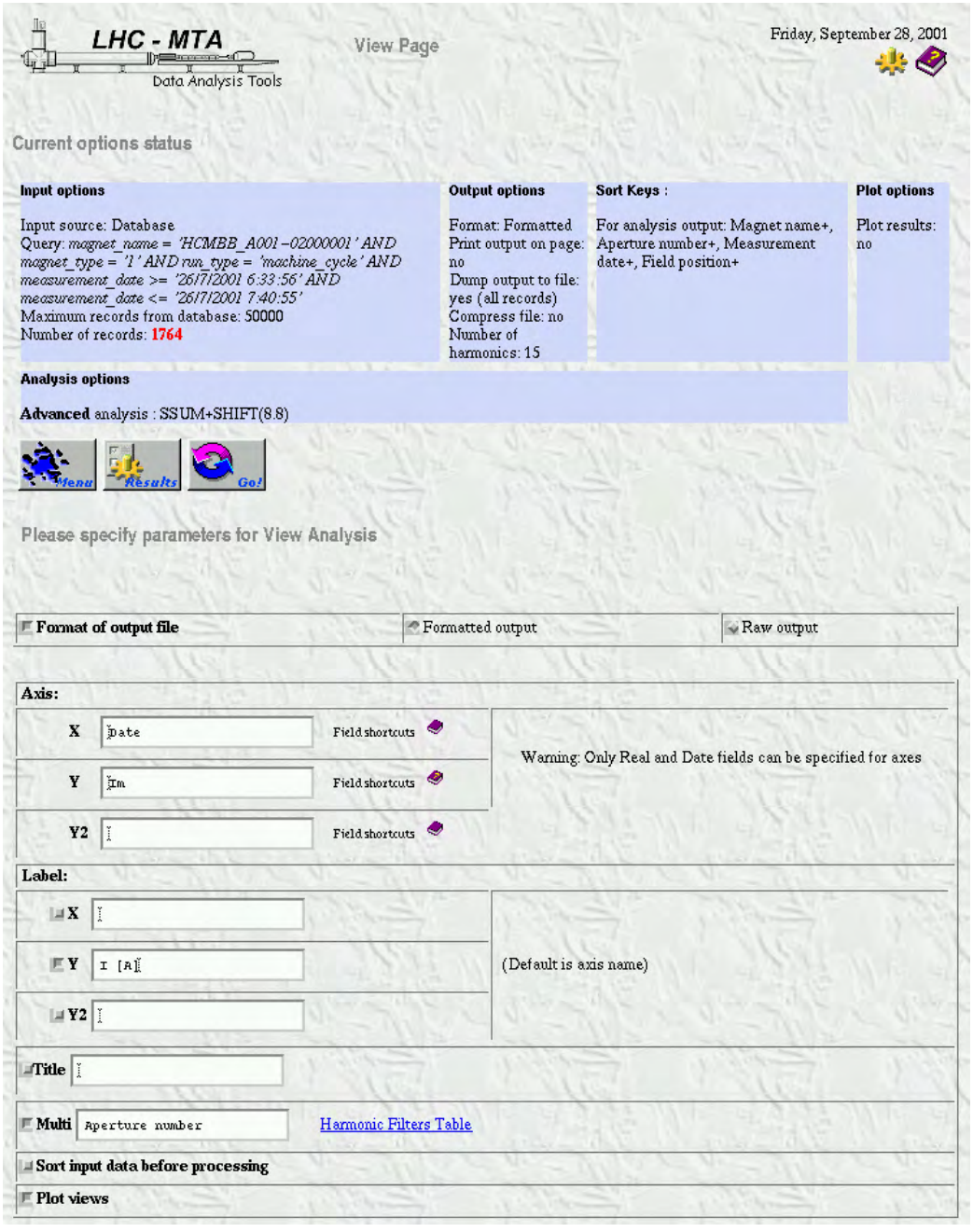
DAP Analysis
Harmonics Results

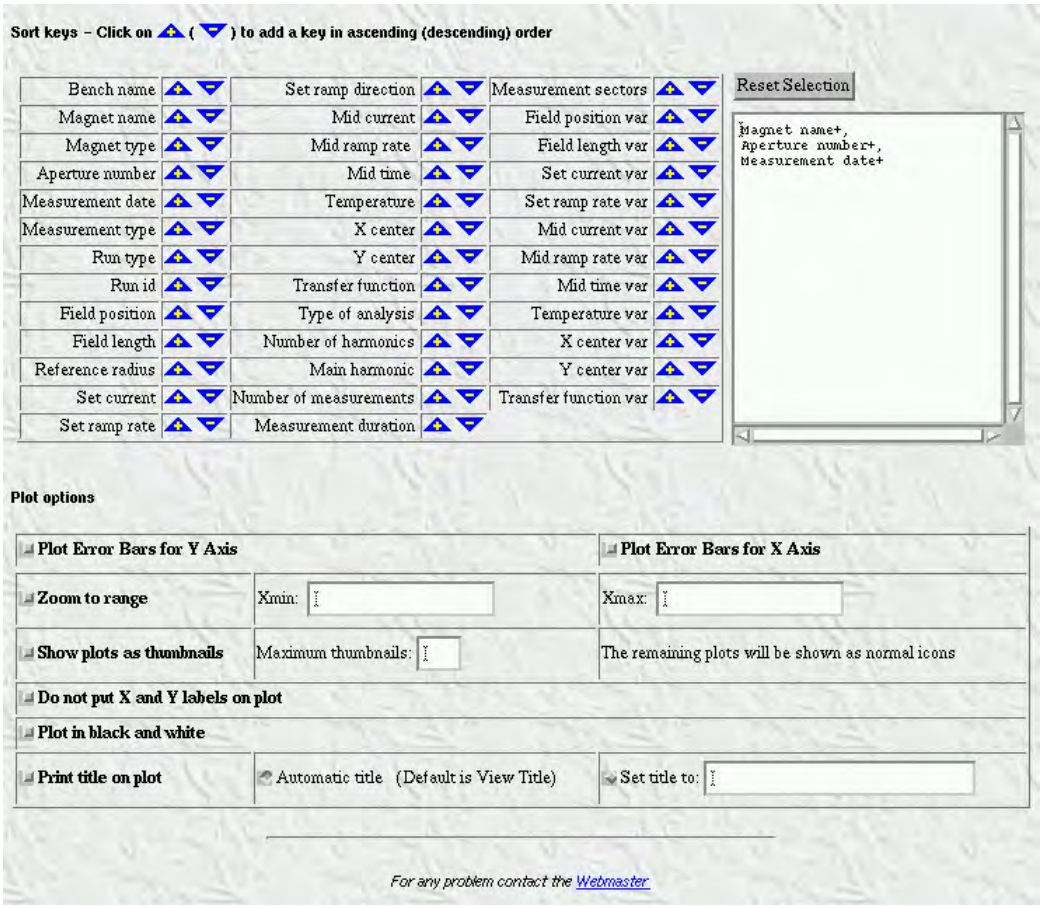


DAP Analysis
Harmonics Results File

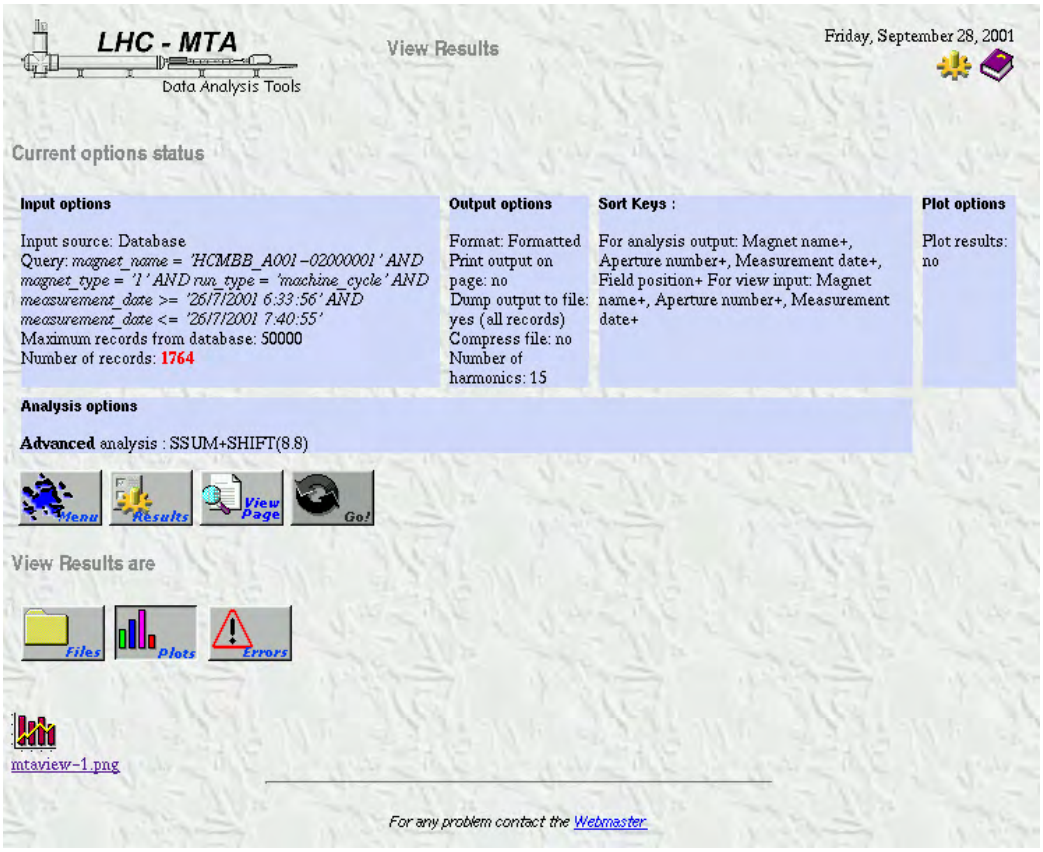
```
Bench name:     SMTP-A1
Magnet name:    HCMBB_A001-02000001
Magnet type:     1
Aperture number:         1
Measurement date:       26/07/2001 06:33:56
Measurement type:       cmp
Run type:       machine_cycle
Run id:  8607
Field position [m]:      0.04870636
Field length [m]:        14.30395
Reference radius [m]:    0.017
Set current [A]:         376.7391
Set ramp rate [A/s]:     75.3338
Set ramp direction:      1
Mid current [A]:         497.4237
Mid ramp rate [A/s]:     9.958975
Mid time [s]:    9.24171
Temperature [K]:         1.98589
X center [m]:   -0.0001851284
Y center [m]:    0.0006027624
Transfer function [T/A, T.m/A]:  0.01011681
Type of analysis:       GAIN+DRIFT+FLUX+AVRG+SPEC:HARM+CLOC+FDWN+ROT+NORM:SSUM+SHIFT(8.8)+SOR
Number of harmonics:    15
Main harmonic:   1
n       Normal [T, T.m, units]: Skew [T, T.m, units]:
1        5.032341        0.01521825
2        0.9134089      -1.56723
3       -2.968804        0.1822258
4       -0.2861264      -0.1480139
5        2.928511        0.2486885
6       -0.006577148     0.002173521
7        0.2340772      -0.04336721
8       -0.06159252      0.009145878
9        0.4131791       0.09740089
10      -0.02633526      0.01502624
11       0.7615809      -0.136751
12       0.1094959       0.09082567
13       0.2116186      -0.2566215
14      -0.02614667     -0.008024626
15       0.01400618      0.04472268
Statistics
Number of measurements:  12
Measurement duration:    0
Measurement sectors:    h023s2223e1w+h023v1821a1w+h023s1617e1w+h023v1015a1w+h023v0409e1w+h023
Field position var:      0.00e+00
Field length var:        0.00e+00
Set current var:         0.00e+00
Set ramp rate var:       0.00e+00
Mid current var:         0.00e+00
Mid ramp rate var:       0.00e+00
```

DAP Analysis
View Input/Output Selection

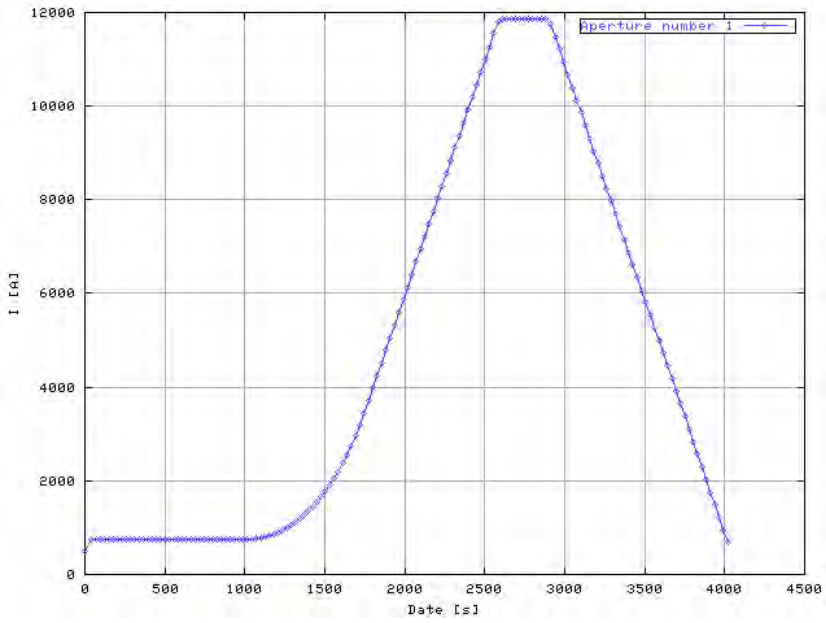



Sort keys – Click on ( ) to add a key in ascending (descending) order
Bench name
Magnet name
Magnet type
Aperture number
Measurement date
Measurement type
Run type
Run id
Field position
Field length
Reference radius
Set current
Set ramp rate
Set ramp direction
Mid current
Mid ramp rate
Mid time
Temperature
X center
Y center
Transfer function
Type of analysis
Number of harmonics
Main harmonic
Number of measurements
Measurement duration
Measurement sectors
Field position var
Field length var
Set current var
Set ramp rate var
Mid current var
Mid ramp rate var
Mid time var
Temperature var
X center var
Y center var
Transfer function var
Reset Selection
Magnet name+,
Aperture number+,
Measurement date+
Plot options
Plot Error Bars for Y Axis
Plot Error Bars for X Axis
Zoom to range
Xmin:
Xmax:
Show plots as thumbnails
Maximum thumbnails:
The remaining plots will be shown as normal icons
Do not put X and Y labels on plot
Plot in black and white
Print title on plot
Automatic title (Default is View Title)
Set title to:
For any problem contact the Webmaster

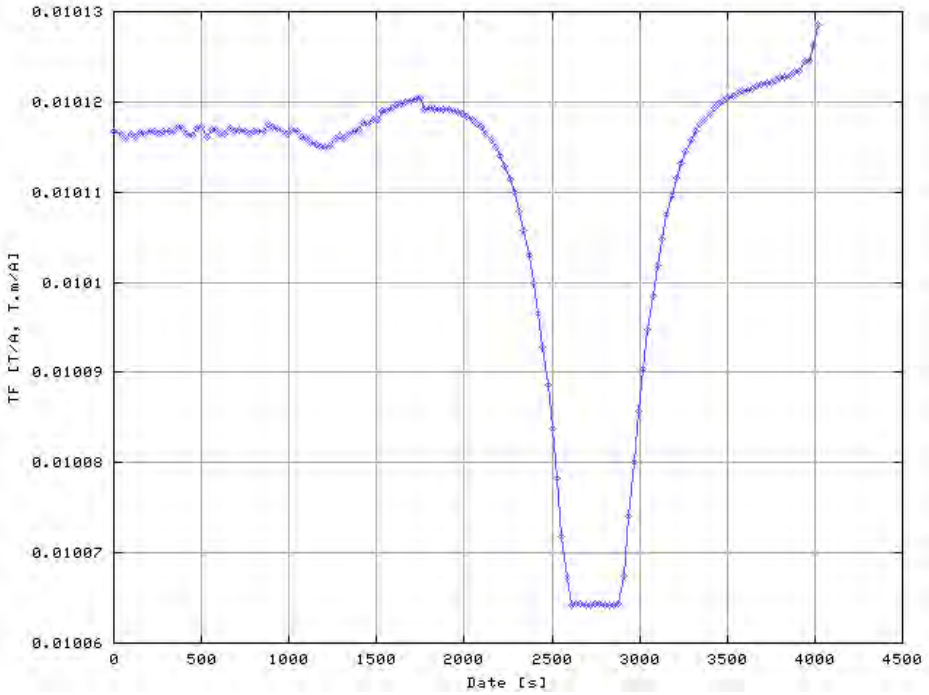
DAP Analysis
View Results



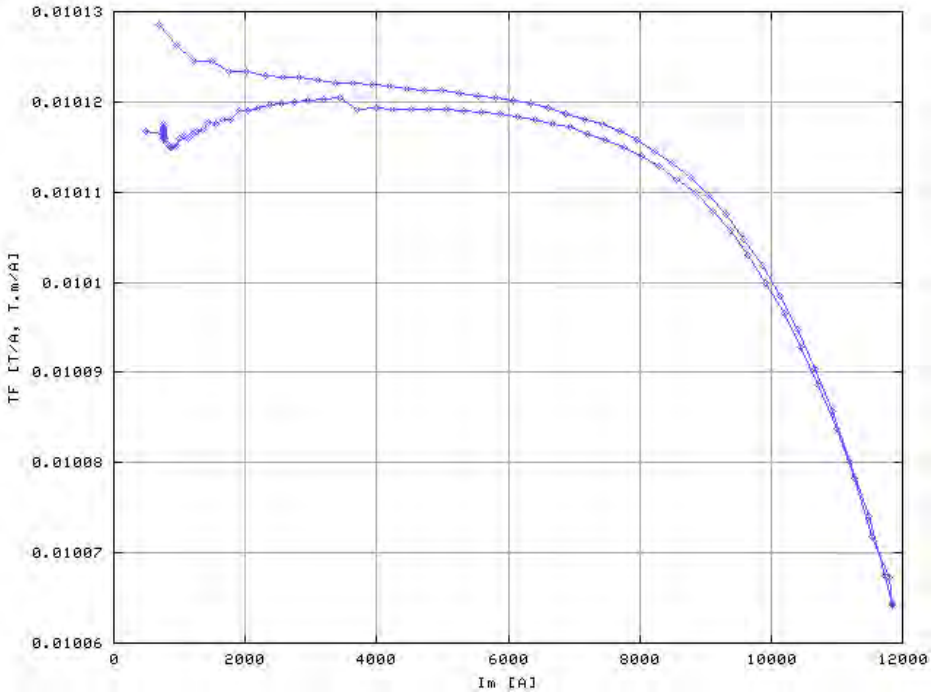
LHC Current Cycle



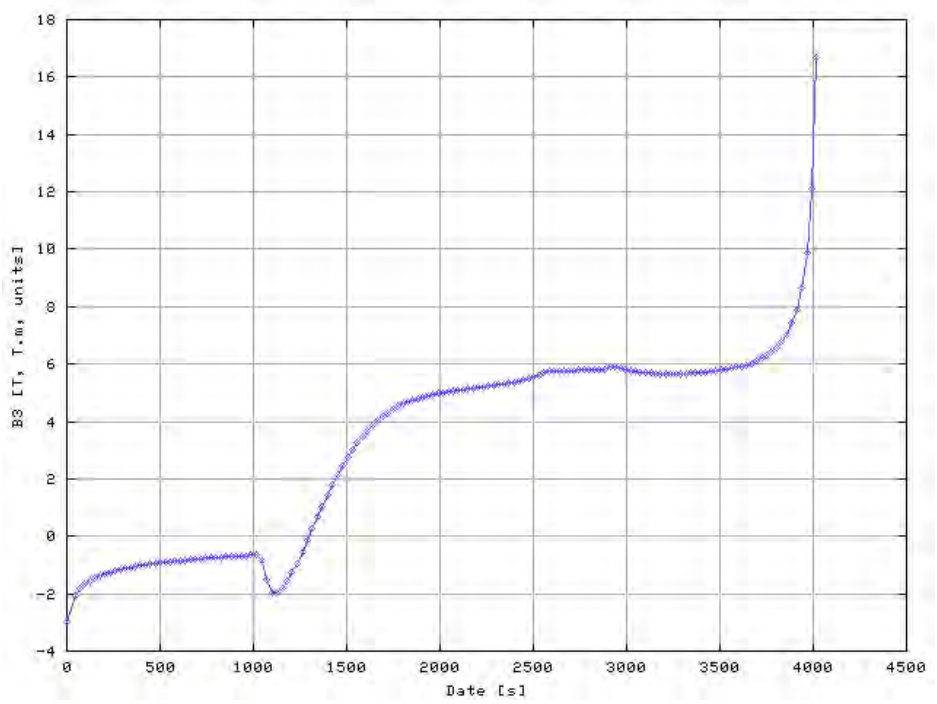
DAP Analysis
Tranfer Function vs Time



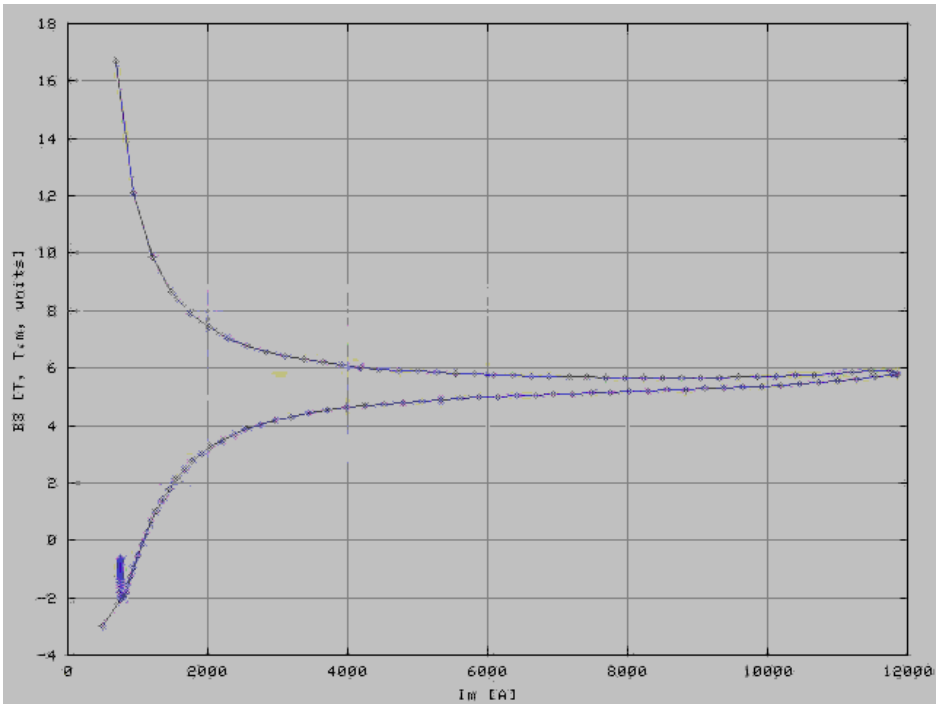
Tranfer Function vs Current



DAP Analysis
B_3 vs Time



B_3 vs Current

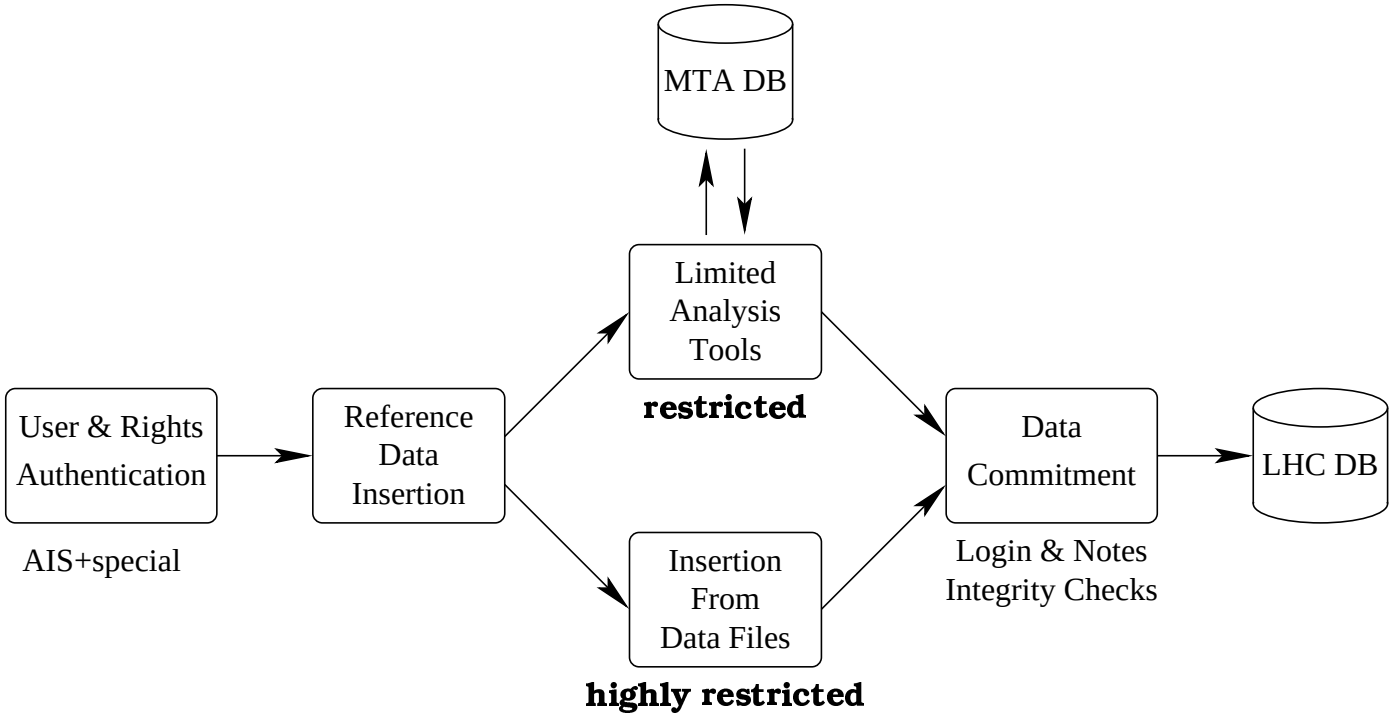


DAP Analysis
The Magnetic Field Model

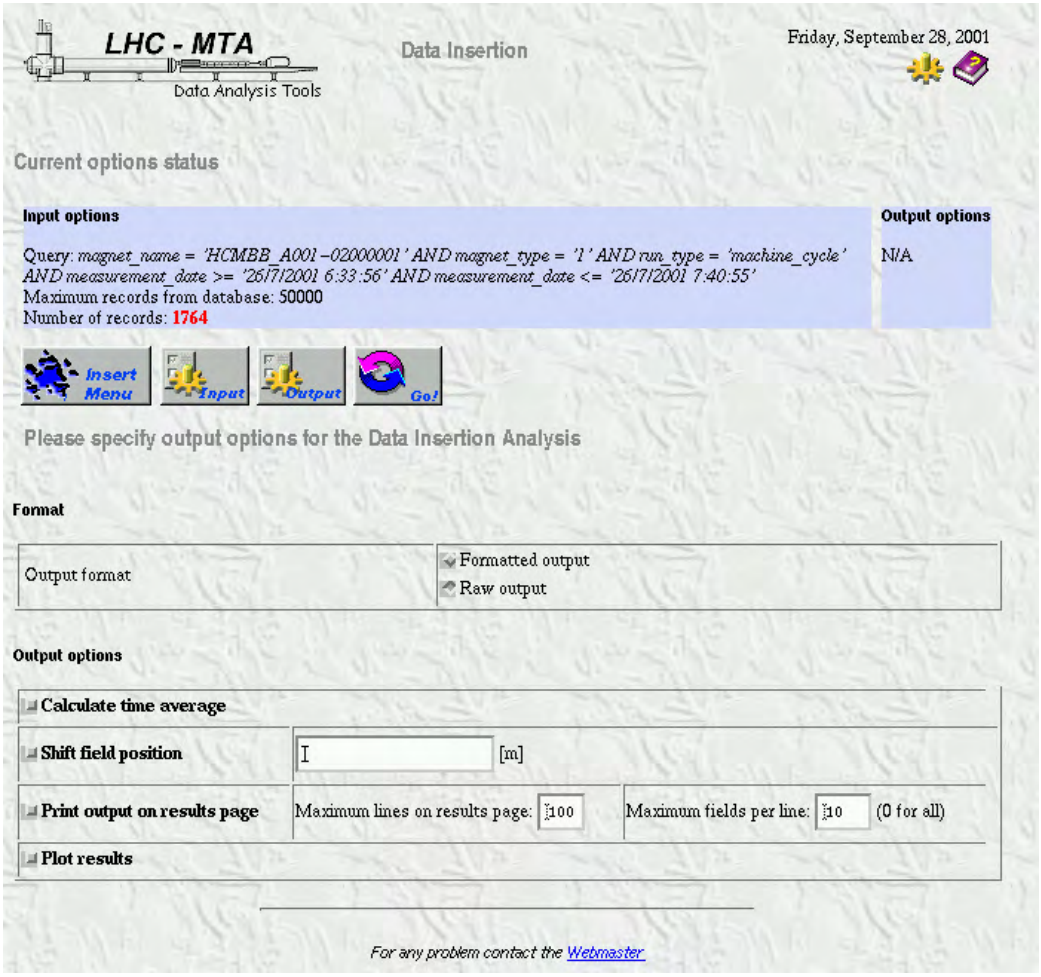
$$
\begin{aligned}
B_n(t, I, dI/dt) &= B_n^{DC} + B_n^{ACS} + B_n^{ACL} \\
&= B_n^{res} + B_n^{geo} + B_n^{dis} + B_n^{mag} + B_n^{sat} + B_n^{edd} + B_n^{dec} + B_n^{sna} \\
&= \alpha_n^{res} + \alpha_n^{geo} I + \alpha_n^{dis} I^3 \\
&\quad \pm \alpha_n^{mag} \left(\frac{I}{I_c}\right)^{n_0} \left(1 - \frac{I}{I_c}\right)^{n_1} \\
&\quad + 1 + \frac{1}{\pi}\left[\arctan\left(\frac{I - I_n^1}{\Delta I_n^1}\right) + \arctan\left(\frac{I - I_n^2}{\Delta I_n^2}\right)\right] \\
&\quad + \alpha_n^{edd} \frac{dI}{dt} \\
&\quad + \sum_{k=1}^{3} \alpha_n^{deck} \left(1 - \exp\left(-\frac{(2k-1)^2 (t - t_0)}{\tau_0}\right)\right) \\
&\quad + \sum_{k=1}^{2} \alpha_n^{snak} \exp(\beta_n^k (I - I_{inj}))
\end{aligned}
$$

- Extracts 21 parameters per magnet field harmonic
- Needs 1 LHC Machine Cycle and 1 Ramps Cycle ($\approx$ 3000 rotating coils measurements, $\approx$ 2h)
- Estimates Transfer Function within 1 unit (limited by the measurement system accuracy)
- Estimates B_3 within 0.05 unit (will be improved) (limited by the knowledge of $I(t)$ and sampling rate)
- Estimates other harmonics better than 0.01 unit (better than LHC tolerances)

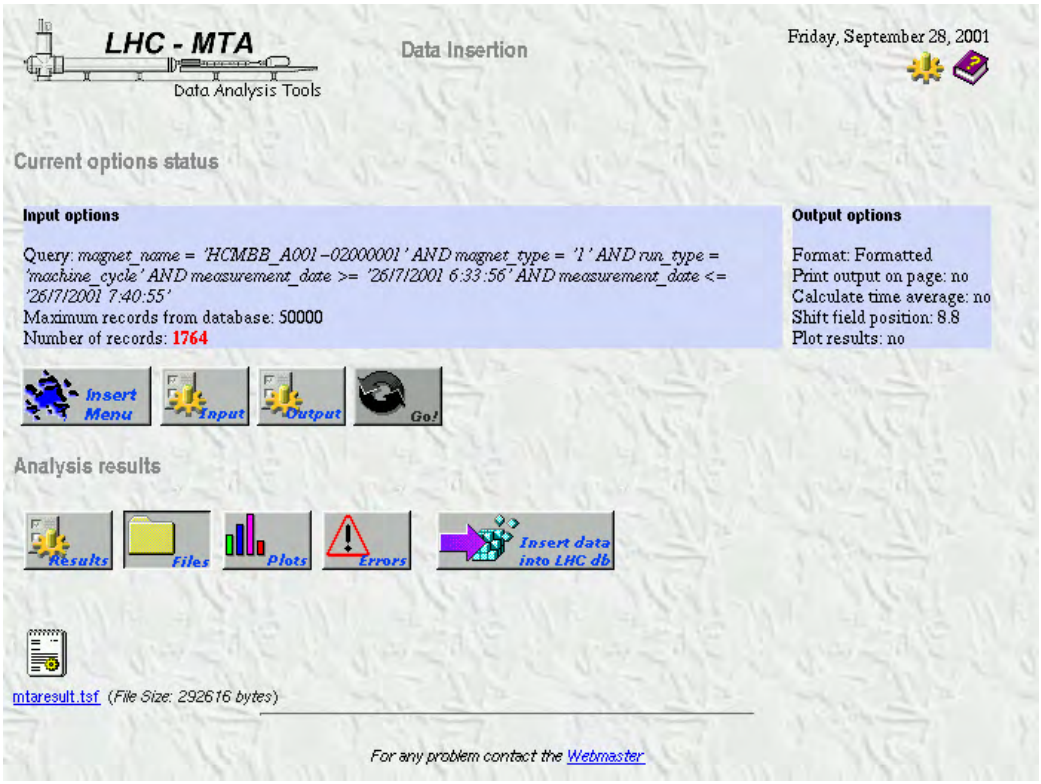
Reference Data Commitment



DAP Analysis
Reference Table Analysis and Output Selection (Highly Restricted)



DAP Analysis
Reference Table Results



DAP Analysis
Reference Table Commit