

**Presentation to Workshop on “Absorbed Dose and Air Kerma Primary Standards”, Paris, 9 – 11 May 2007**

# **Improvements to the UK Primary Standard Therapy Level Electron Beam Calorimeter**

**Mark Bailey, GA Bass, E Kirby, ND Lee, GA Mapp, DR Shipley**

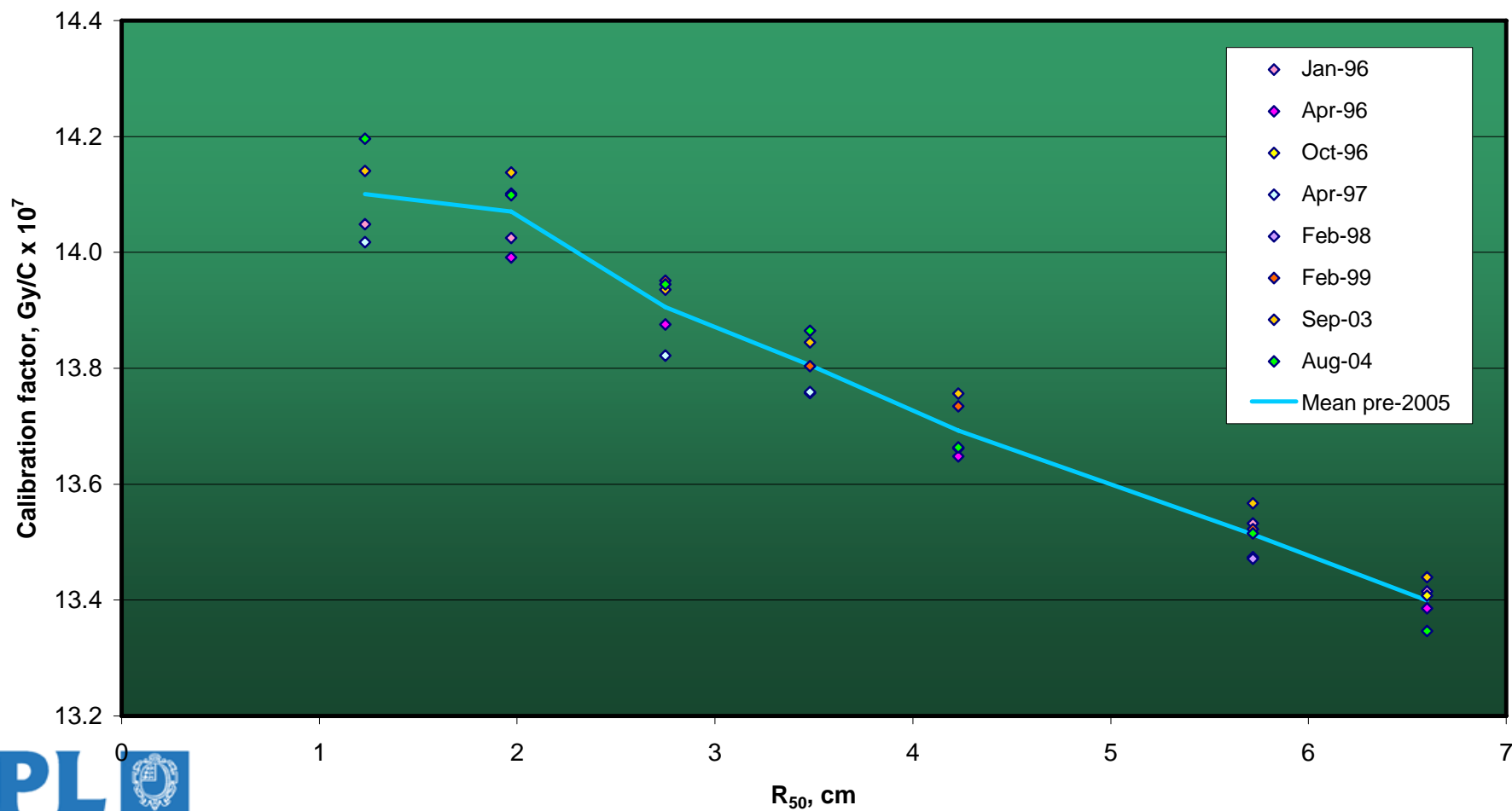
1. History – the Codes of Practice
2. The UK Primary Standard Therapy Level Electron Calorimeter
3. Redesign of calorimeter body and electronics
4. Thermal modelling and new analysis procedure
5. Results obtained
  
6. Gap effect calculation – NPL Grid
7. The UK Therapy Level Primary Standard Absorbed Dose Calorimeter – The Next Generation

## History – Codes of Practice, calorimeter development

- Dosimetry in UK based on absorbed dose to water using graphite calorimeters, in Codes of Practice dating from 1990 (photons) and 2003 (electrons)
- 2003 IPEM Electron therapy-level dosimetry Code of Practice based on calibrations using the electron calorimeter
- 2005: Problems with noise, interference, and ageing materials and electronics on the electron calorimeter made it impossible to carry out a good series of measurements. ***Refurbishment necessary***
- 2006: Improvements made to housing, electronics, analysis techniques for the electron calorimeter to reduce uncertainties
- 2007: Experience from this fed back into design for next generation primary standard graphite calorimeter at NPL

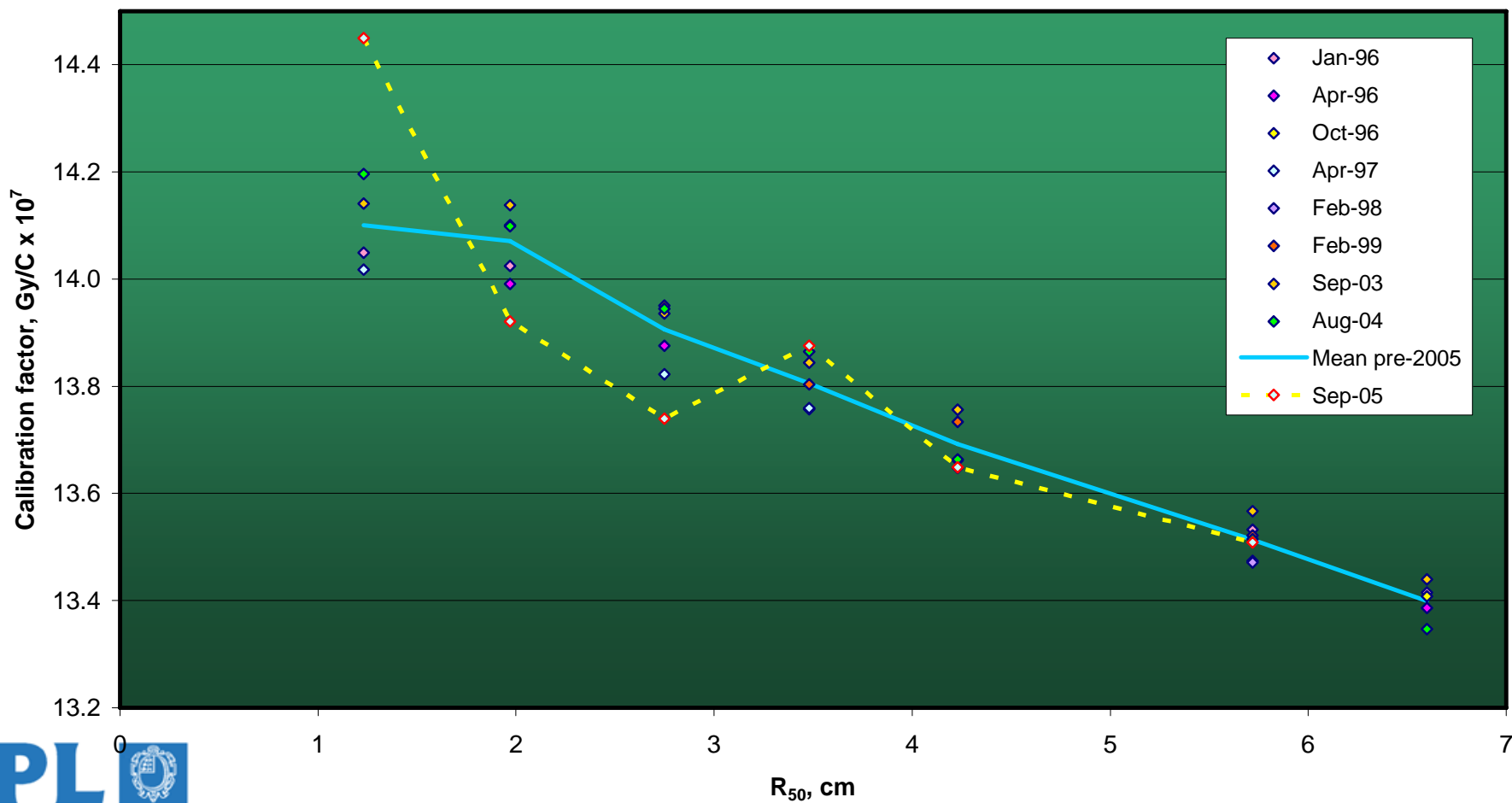
# Calibration of working standard NACP-02 chamber – up to 2004

NPL NACP-02 Chamber 3009  
Up to 2005



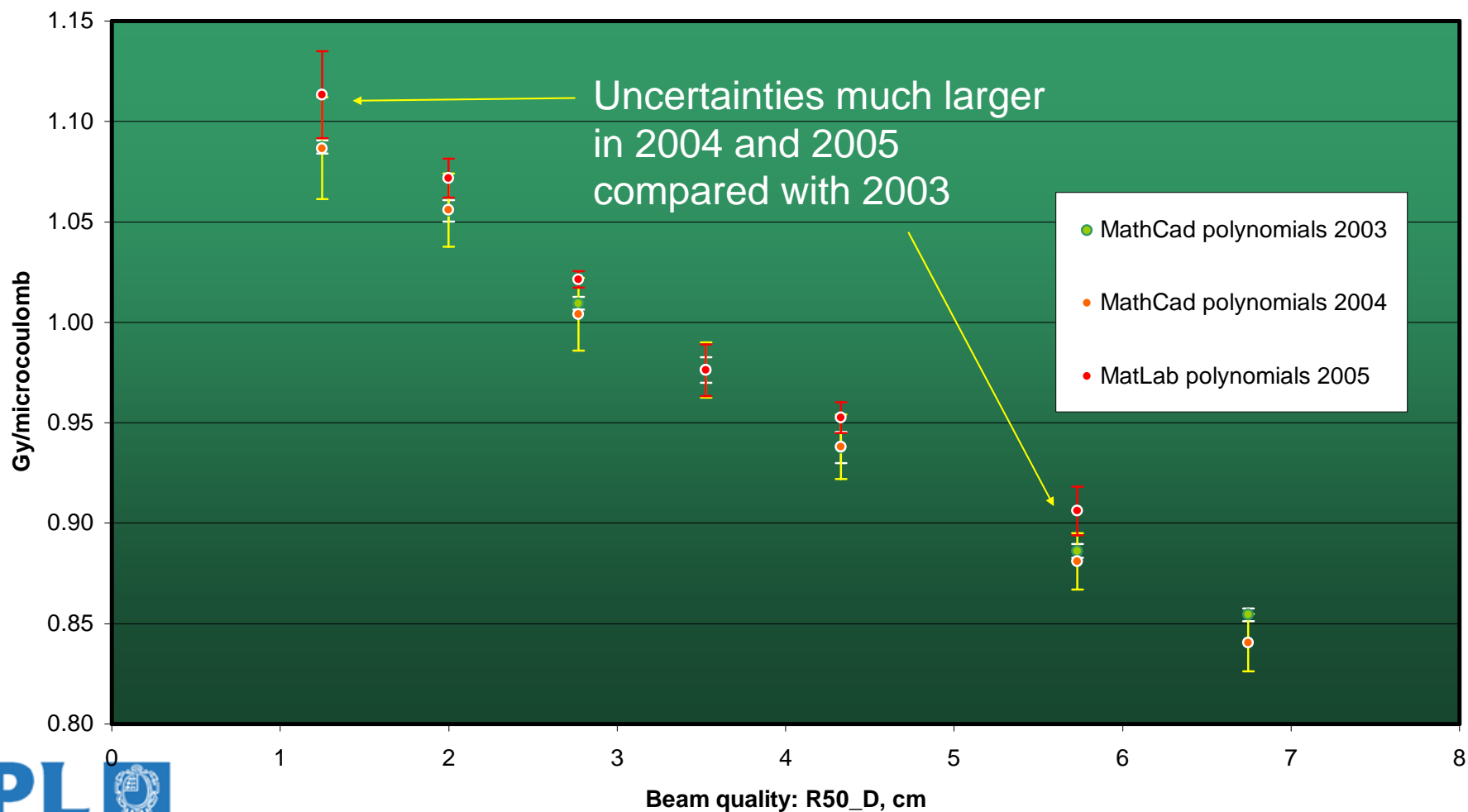
# Calibration of working standard NACP-02 chamber - 2005

NPL NACP-02 Chamber 3009  
including 2005 data  
(2005 data excluded from mean)



# Calorimeter/beam monitor ion chamber response

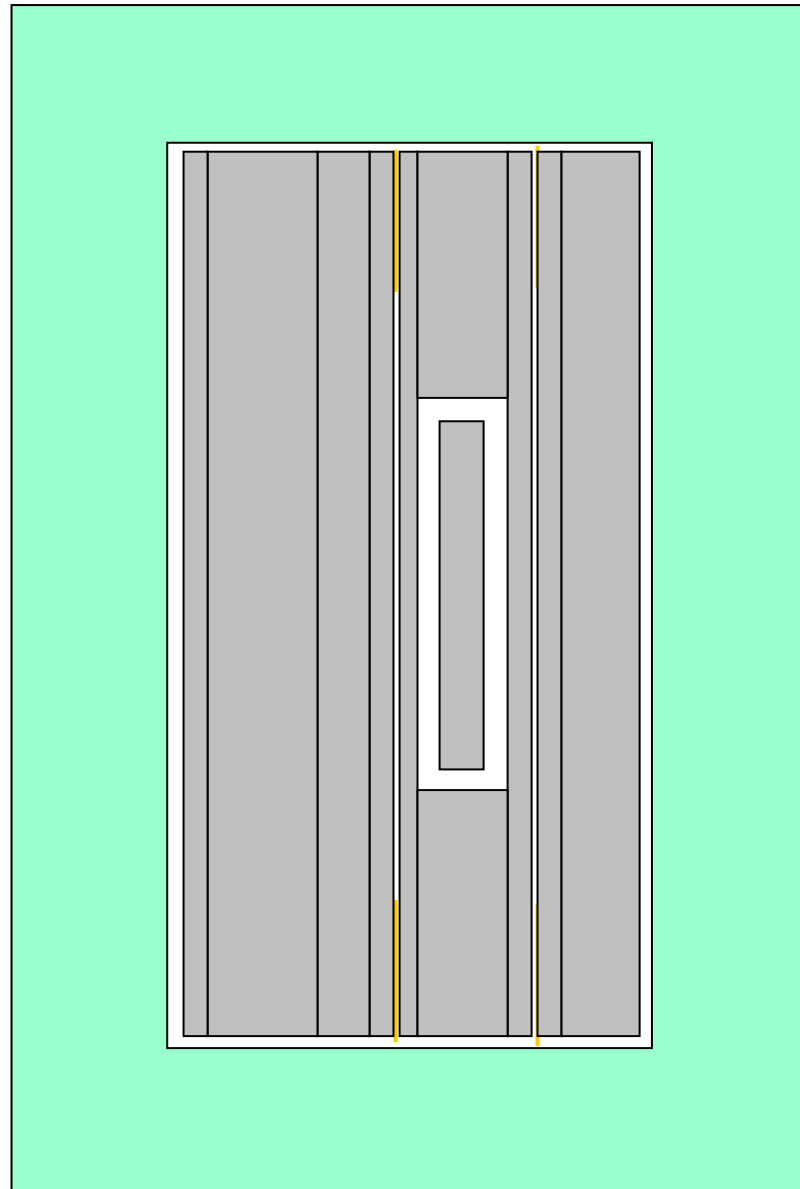
Calorimeter/monitor ratios for data 2003 - 2005 (normalised against 2006/7)



# Electron calorimeter – general layout

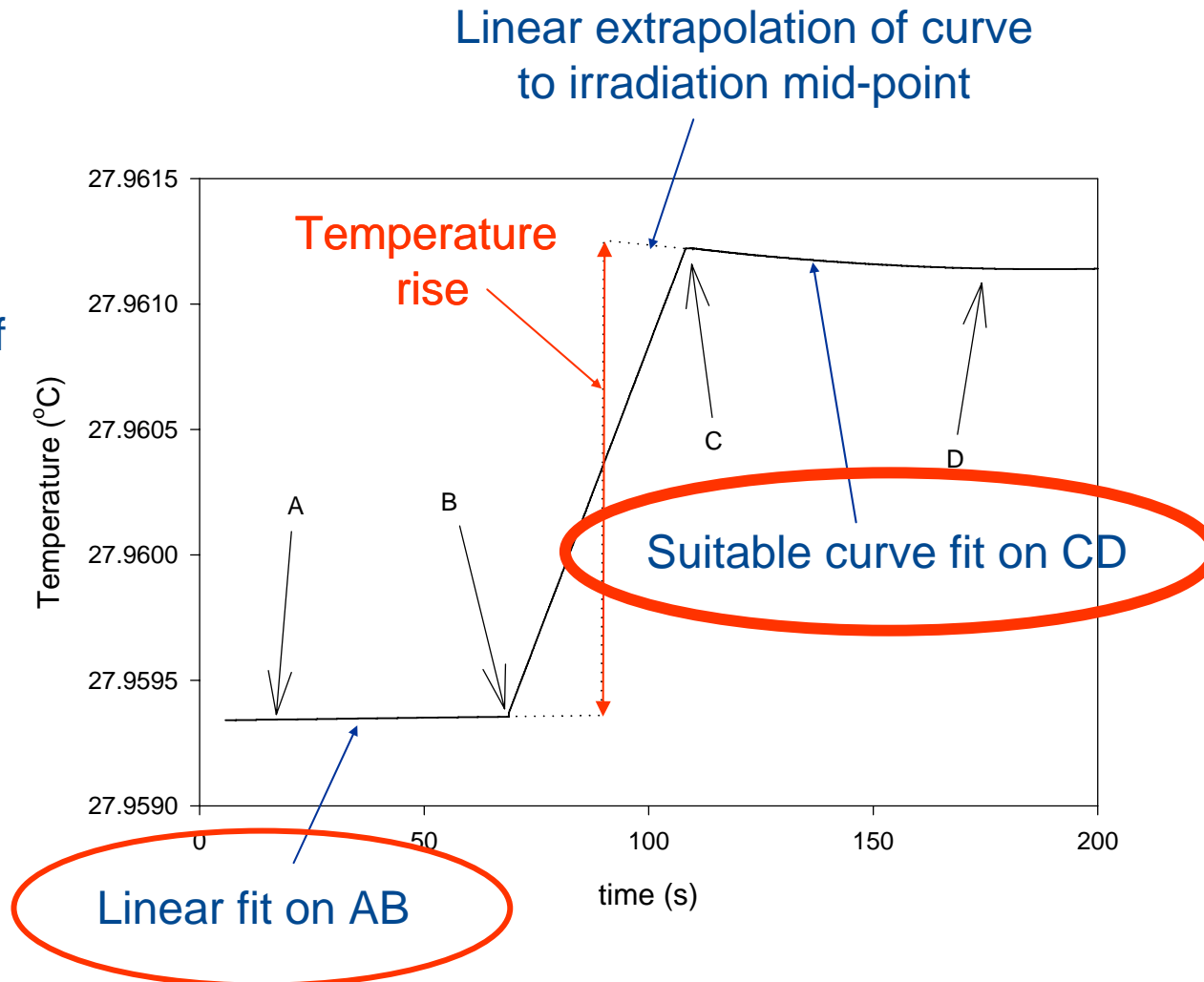
Absorber: 2mm thick,  
5cm diameter graphite  
disc.

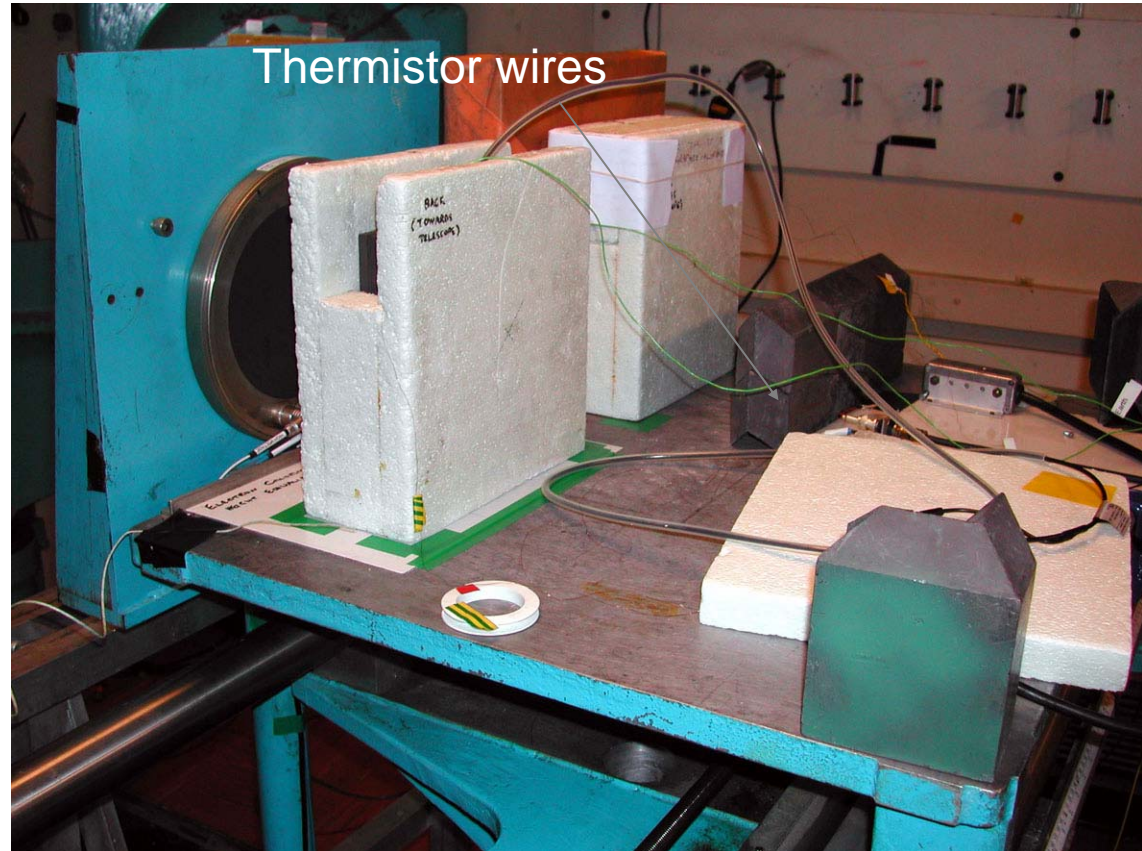
22k $\Omega$  NTC thermistors  
embedded within disc to  
measure temperature.



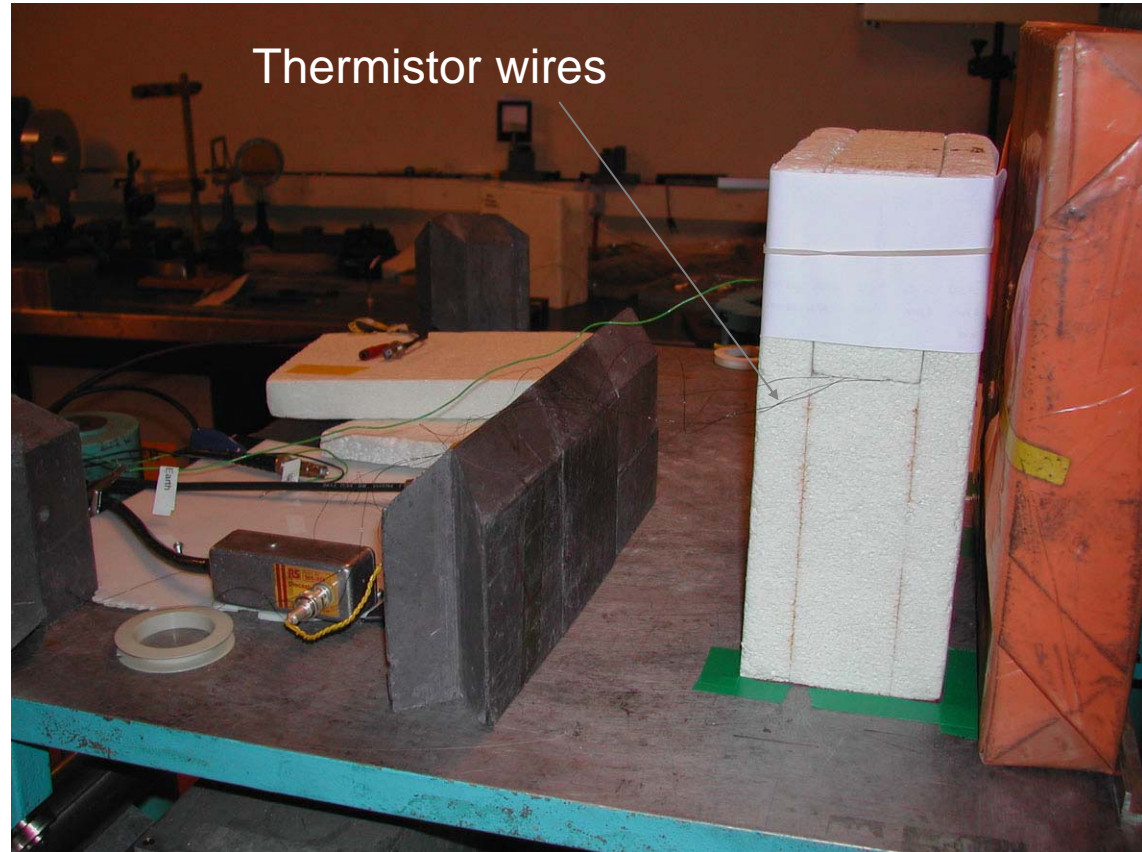
# Principle of operation

- Quasi-adiabatic measurement of temperature rise during irradiation
- Requires good temperature calibrations and good knowledge of heat capacity of absorber, and *very good* resistance to noise





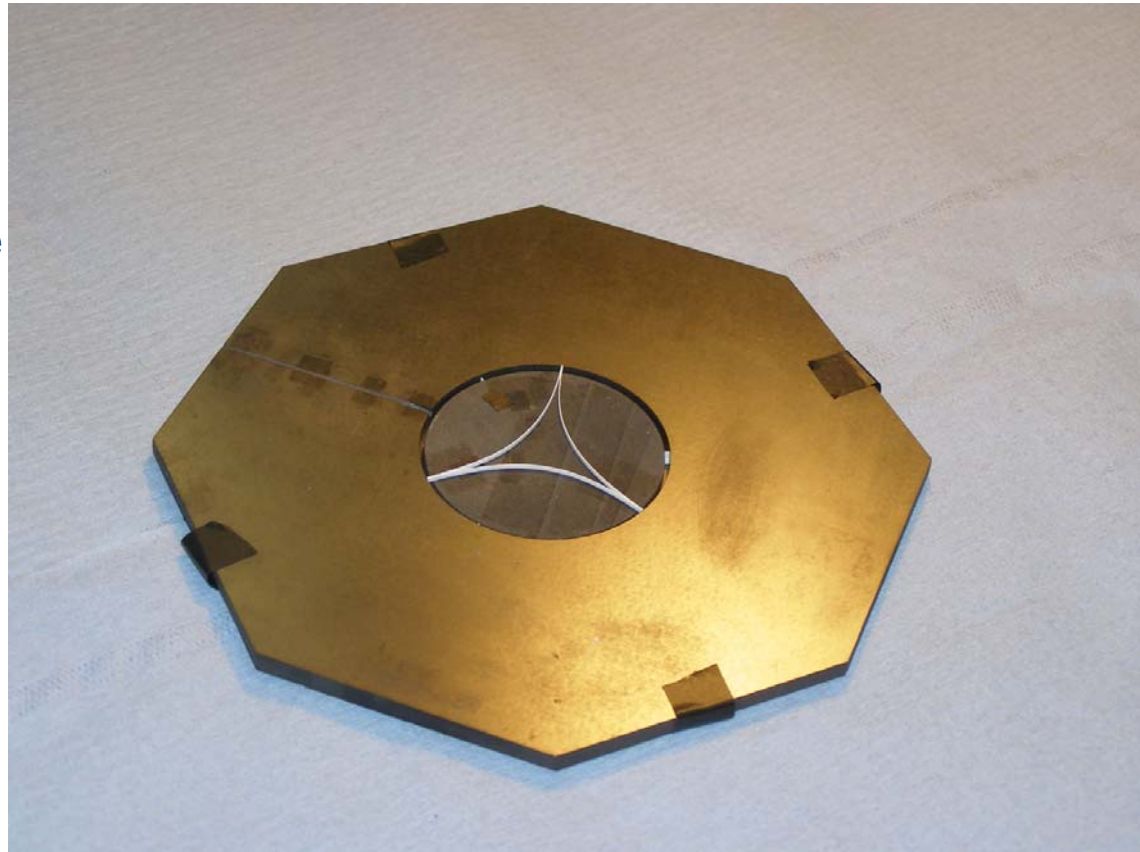
# Calorimeter up to 2005



- Historically, MathCAD and then MatLab used to fit polynomial functions on interval CD after irradiation, which are then extrapolated back linearly (which allows correctly for increase of heat flow from zero during the irradiation) to irradiation midpoint
  - Drawback: Fixed intervals and weightings, mean no account taken of goodness of data (...fine if data are good!)
  - May contribute significantly to uncertainty
- New: MatLab used to provide fits based on polynomials and sums of exponential functions, then Excel used to analyse output and select good data. Functions chosen based on results from simple thermal modelling.
  - Criterion: Convergence in extrapolation to mid-time of temperature rise
- Advantages:
  - Inclusion of exponential functions, based on the physics of heat transfer
  - Can exercise control over data included in final estimate
  - Reduced statistical contribution to uncertainty

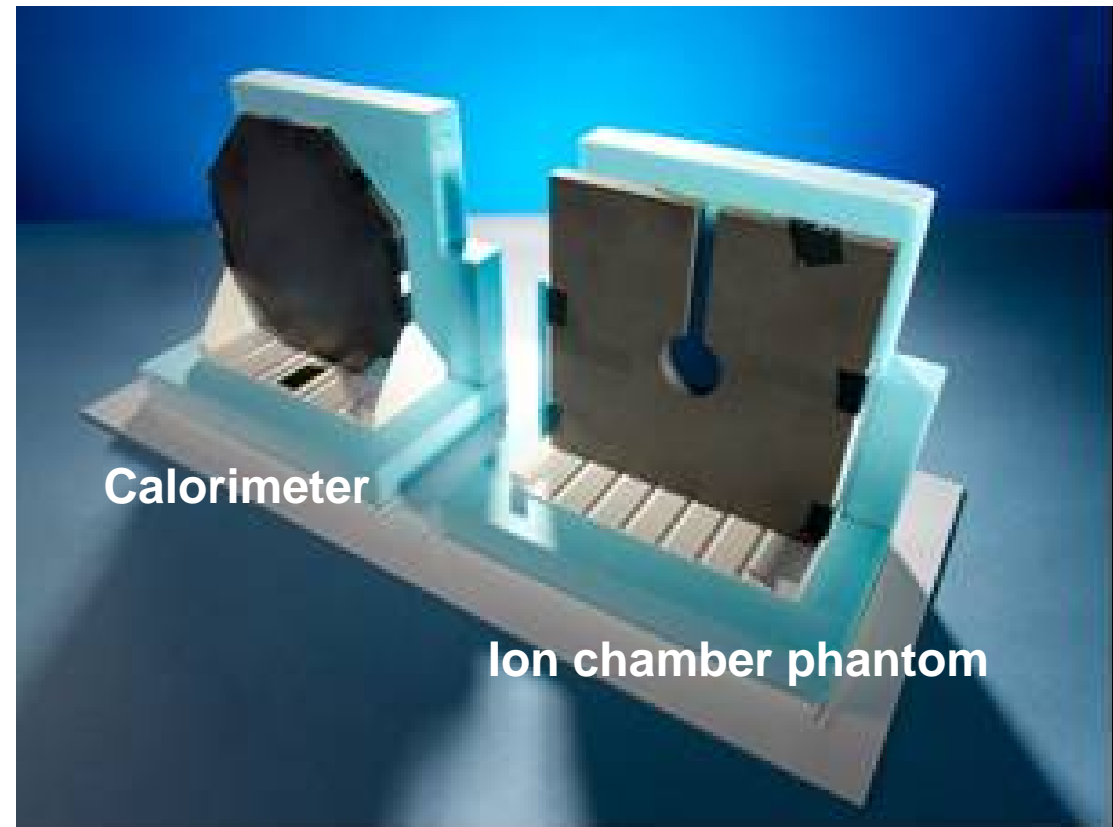
# New physical arrangements

- Original core supports had been glued-on beads of expanded polystyrene
  - Imprecise location
  - Aged due to accumulated dose
- New supports: Sprung, thin polystyrene strips
  - Hold core in precise location
  - No glue involved, minimises impurity uncertainties
  - Contact area with core actually less than with original supports



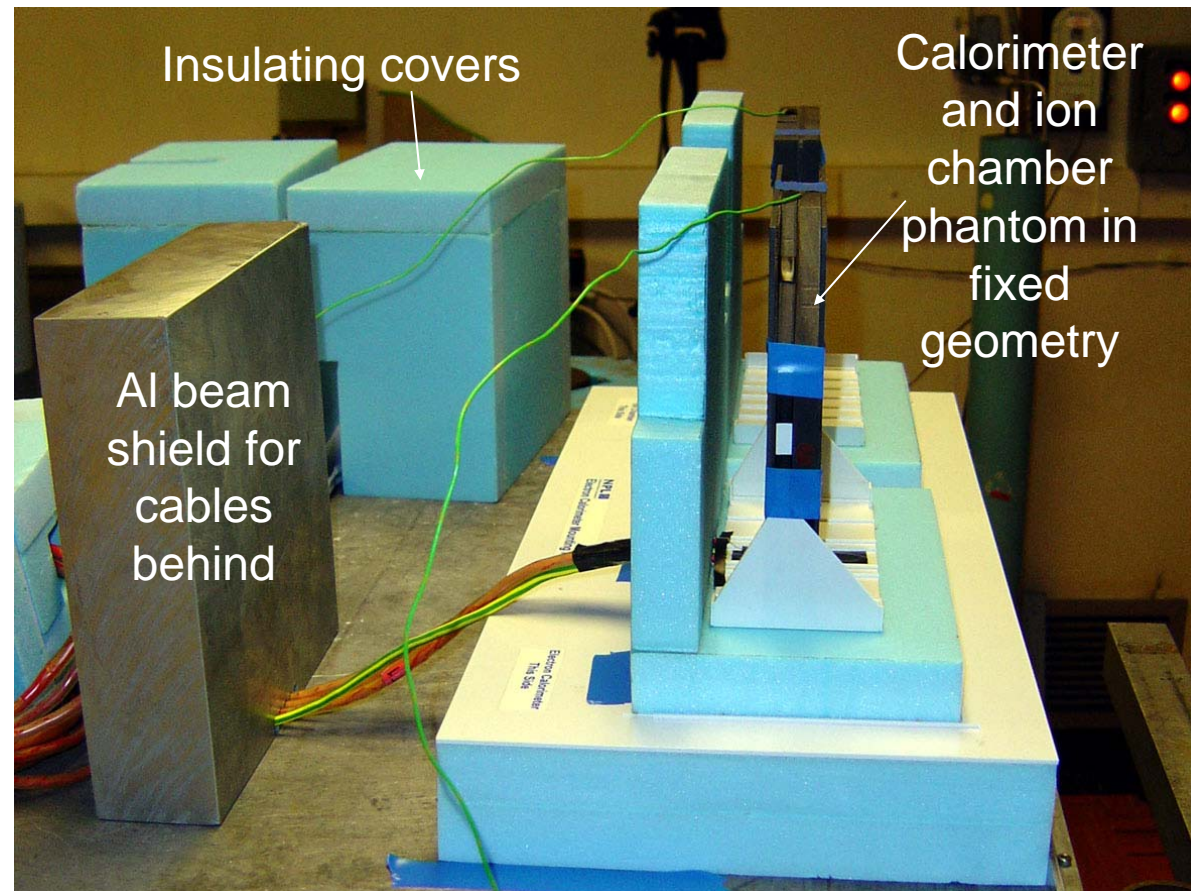
## New physical arrangements (continued)

- New mountings for calorimeter core and chamber phantom
  - Ensures measurement depths correctly set
  - Ensures cables properly protected
  - Cables well-wrapped and sent to back from beneath calorimeter body



## New physical arrangements (continued)

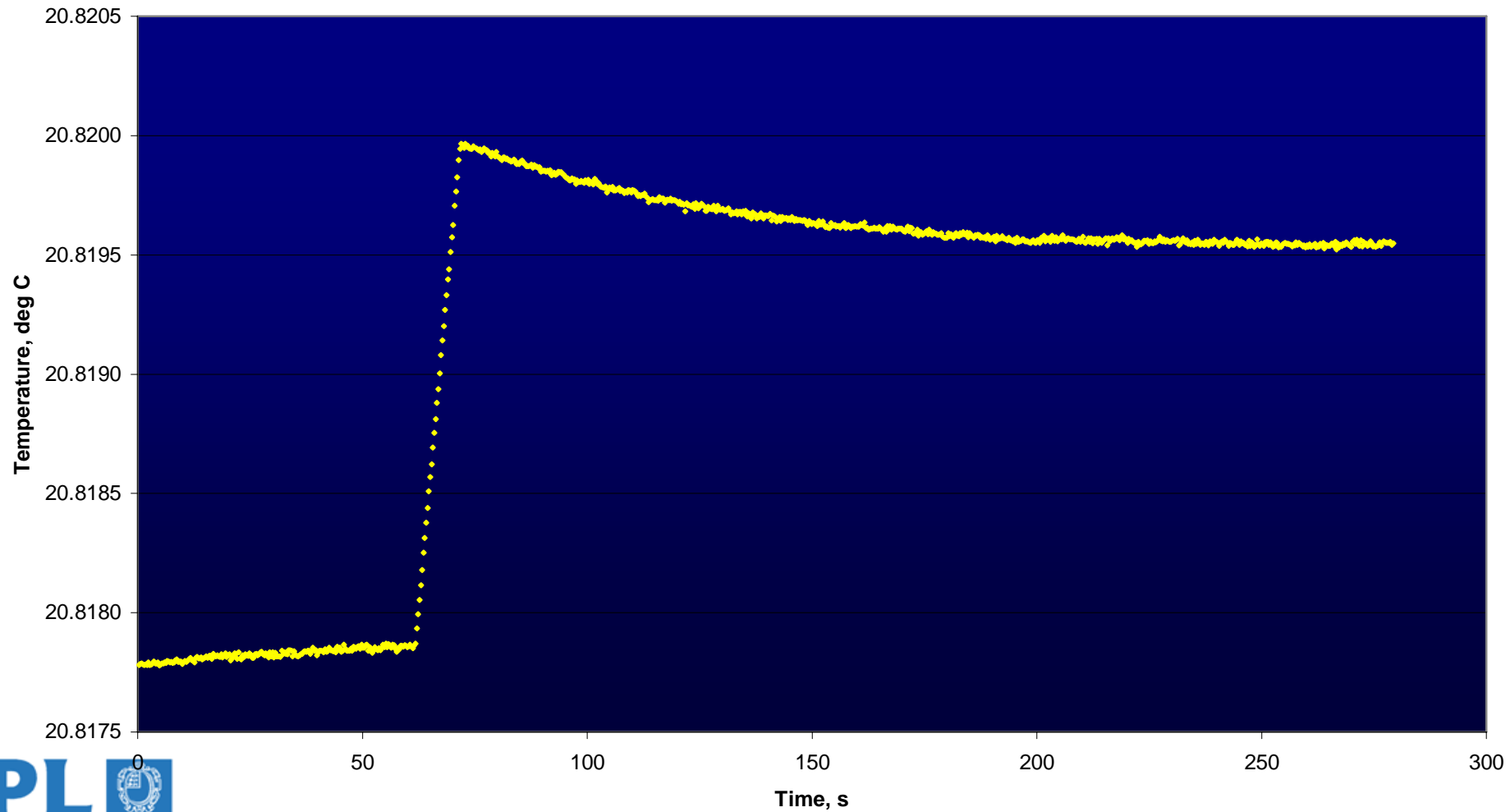
- New mountings for calorimeter core and chamber phantom
  - Ensures measurement depths correctly set
  - Ensures cables properly protected
  - Cables well-wrapped and sent to back from beneath calorimeter body



- New Keithley 2182A nanovoltmeters on Wheatstone bridges
  - Low noise
- New Wheatstone bridges with Vishay sealed high-precision resistors, with built-in preamp stages for input to nanovoltmeters
  - Higher signal-to-noise ratio than previously
- Care taken with thermistor cables including:
  - Taping all sharp edges inside graphite assembly
  - Protecting thermistor cables in screened insulating sleeves
  - Using twisted-pair screened cables back to control room
  - New signal earth arrangements, careful avoidance of earth loops etc.

# A real run with the new setup

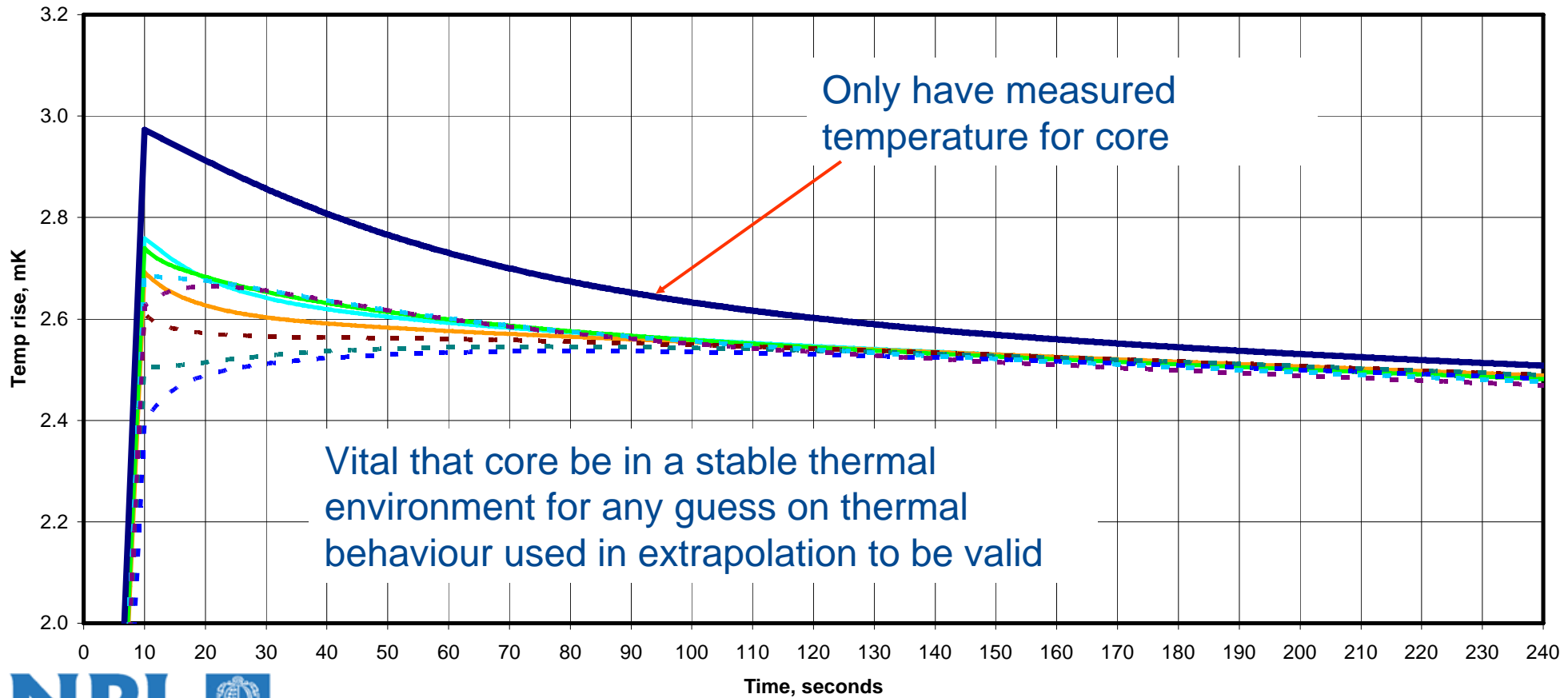
10 MeV Run 4 15 Sept 2006



- Thermal modelling assumptions:
  - Thermal conductivity of graphite much greater than that of air
  - Thermal behaviour dominated by heat transfer between components
- Model developed using Excel to simulate core behaviour
  - Using Excel allows easy change of parameters such as component size, initial conditions, air gaps between buildup plates etc.
  - Model used to check behaviour of analysis methods
- The great disadvantage of course, is that the analysis process involves an **extrapolation!**
- Therefore:
  - Expect polynomial-based solutions particularly, to have a significant uncertainty
  - Motivation to use a more physics-based approach as far as possible

# Model behaviour

Temperature curves for core (dark blue, solid), jackets (pastel, solid) and buildup/backscatter plates (dashed)

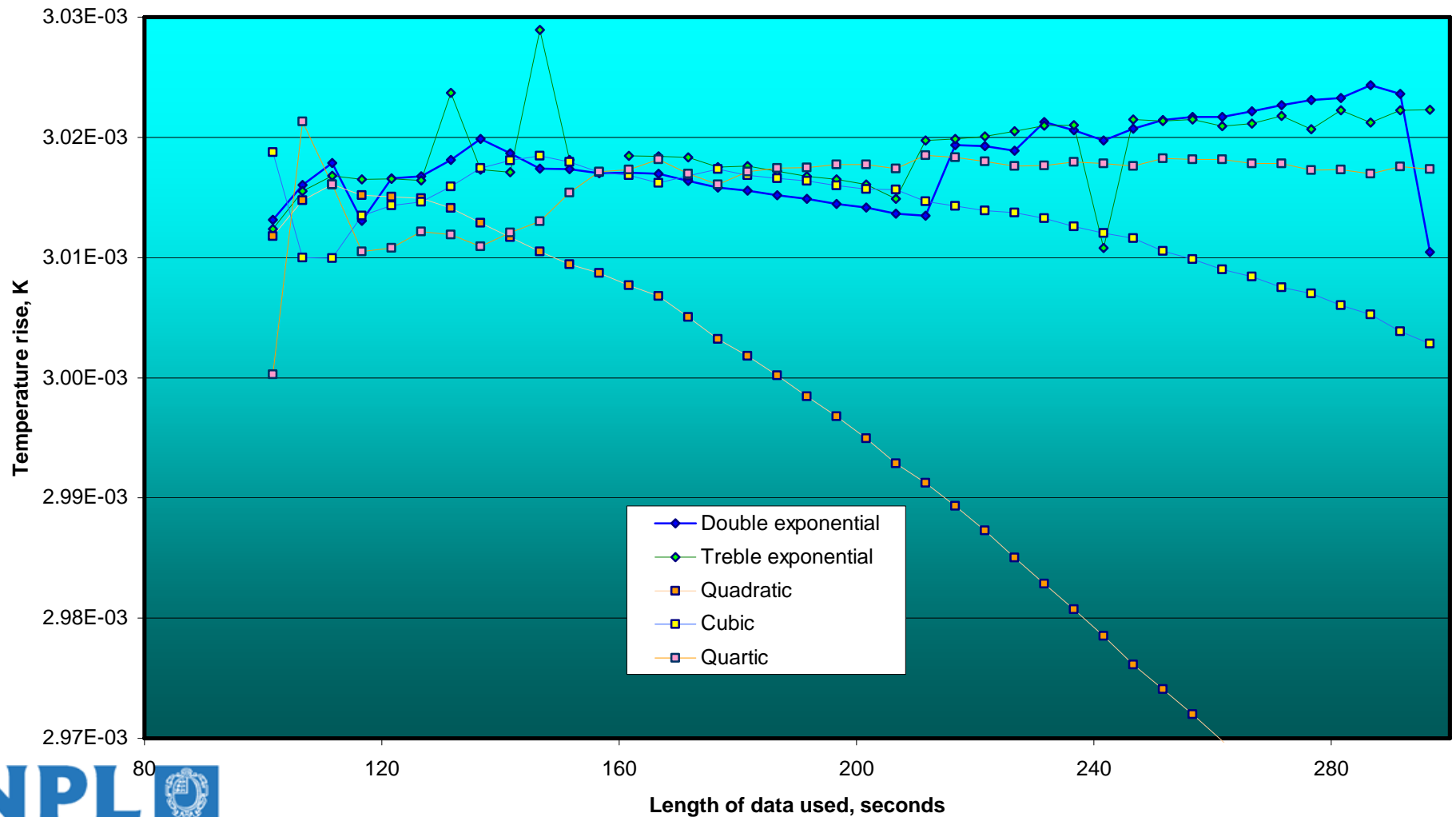


## New analysis technique

- MatLab script takes text output from calorimeter runs, fits polynomials and exponential-based functions as follows
  - Quadratic polynomial,  $A + Bt + Ct^2$
  - Cubic polynomial,  $A + Bt + Ct^2 + Dt^3$
  - Quartic polynomial,  $A + Bt + Ct^2 + Dt^3 + Et^4$
  - Function based on two exponentials,  $Ae^{-Bt} + C(1 - e^{-Dt})$ , with pre-heat linear fit subtracted
  - Function based on three exponentials,  $Ae^{-Bt} + Ce^{-Dt} + E(1 - e^{-Ft})$ , with pre-heat linear fit subtracted
- Linear extrapolations of temperature rise at irradiation mid-time calculated
- Excel then used to examine and analyse the results from these fits, giving final value of absorbed dose to monitor ion chamber ratio with estimate of uncertainty

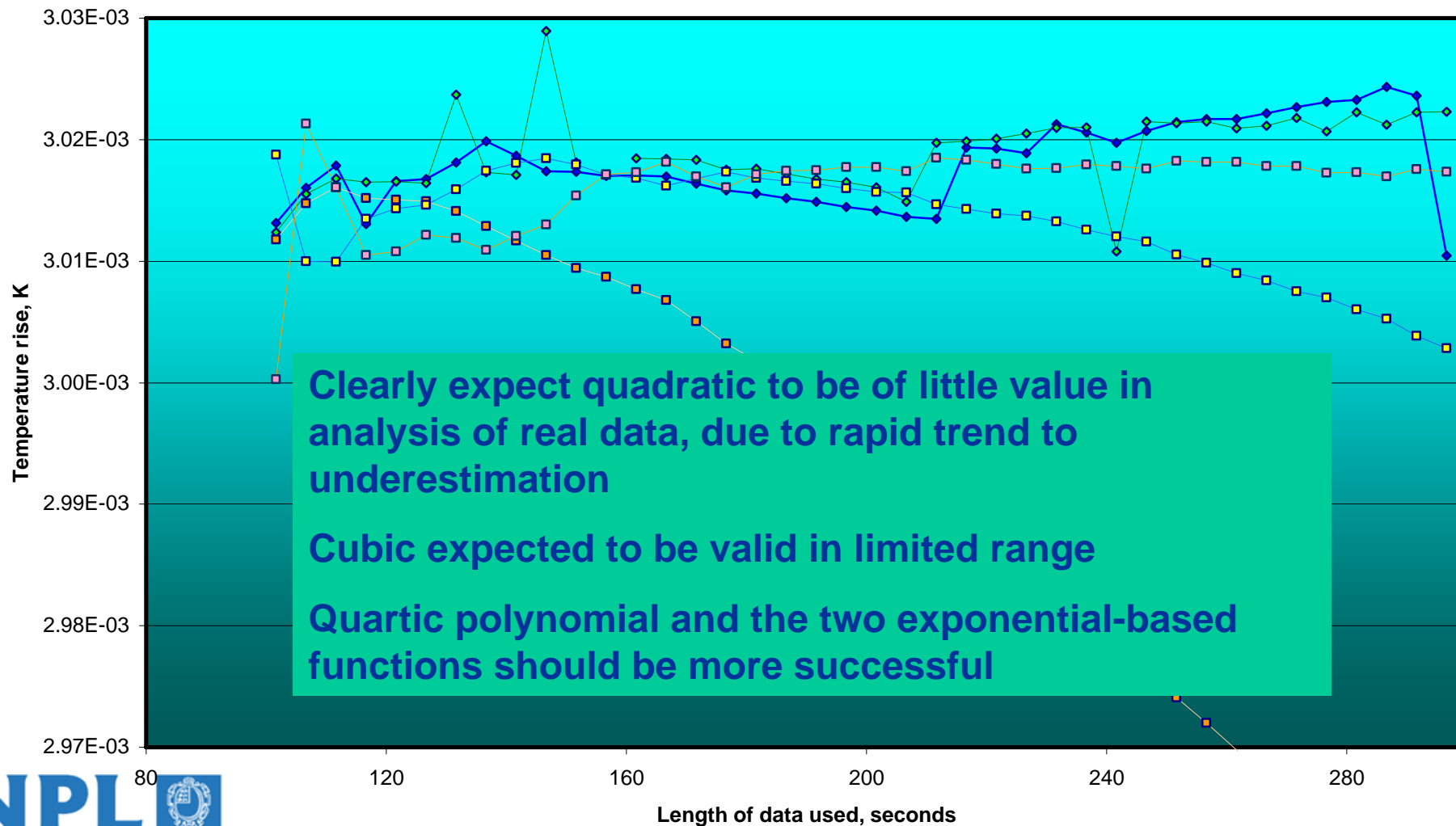
# Analysis: Results from simulated data

10 MeV, simulation



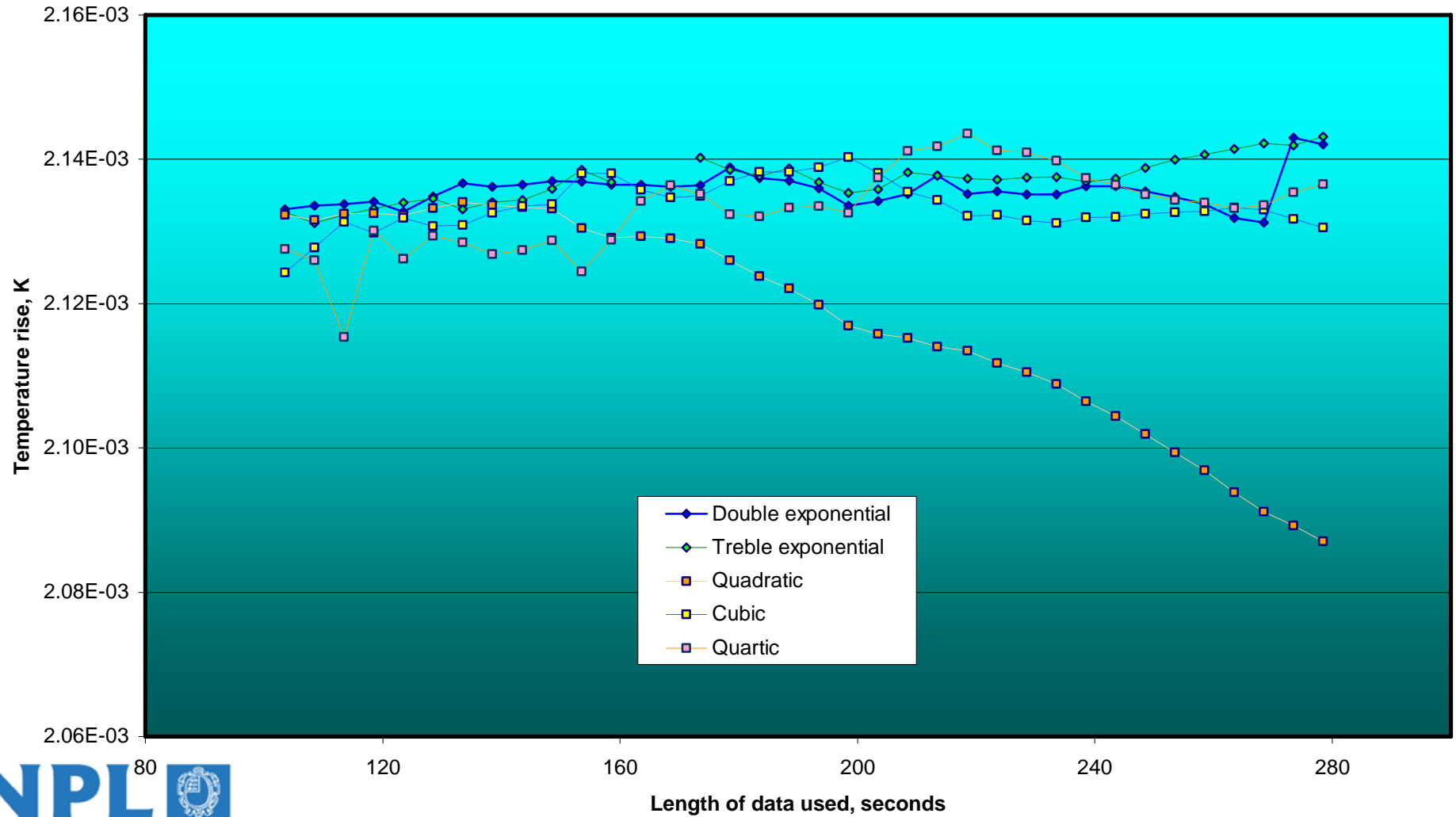
# Analysis: Results from simulated data

10 MeV, simulation



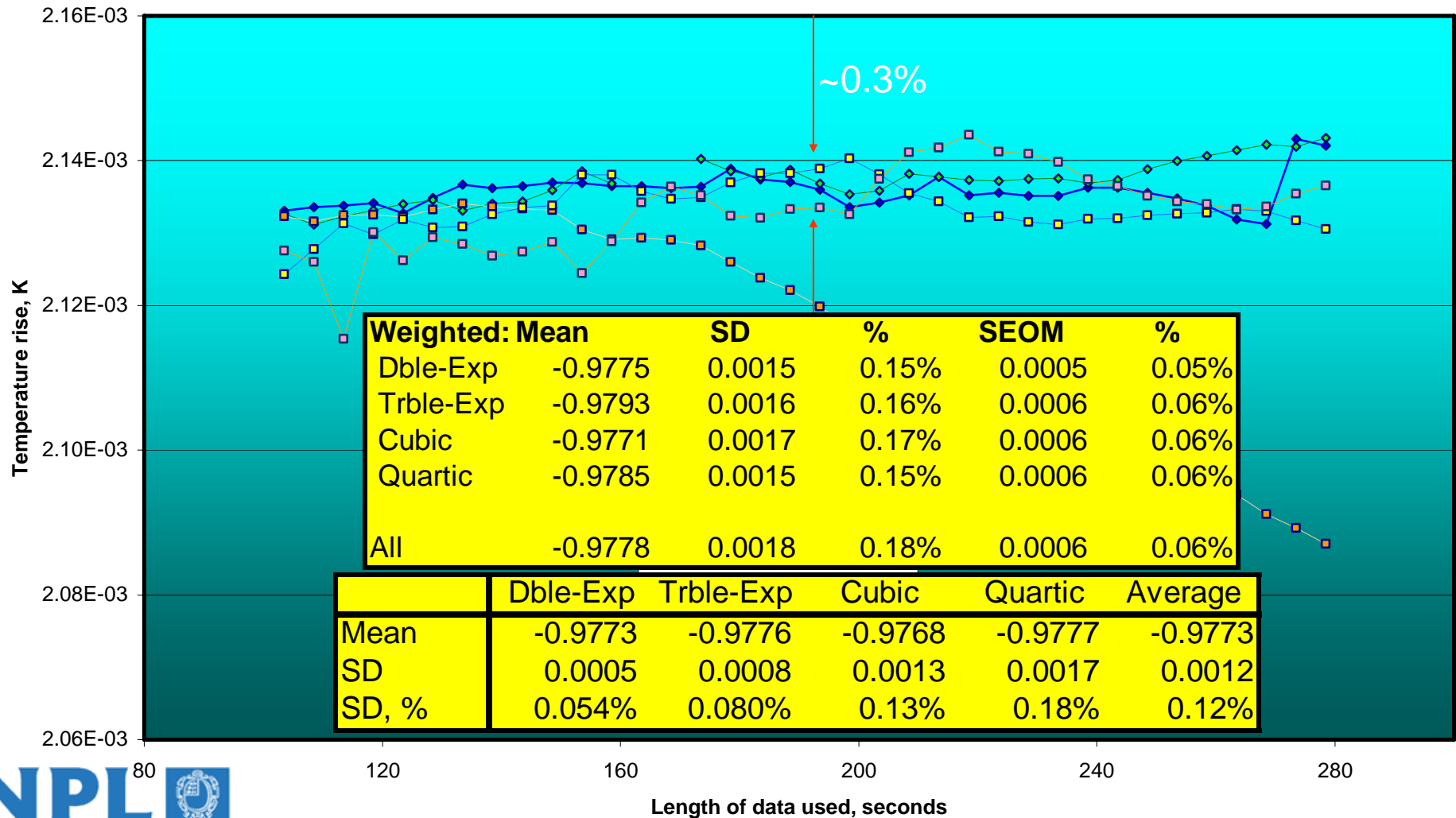
# Analysis: Results from real data

10 MeV, 15 Sept 06, Run 4



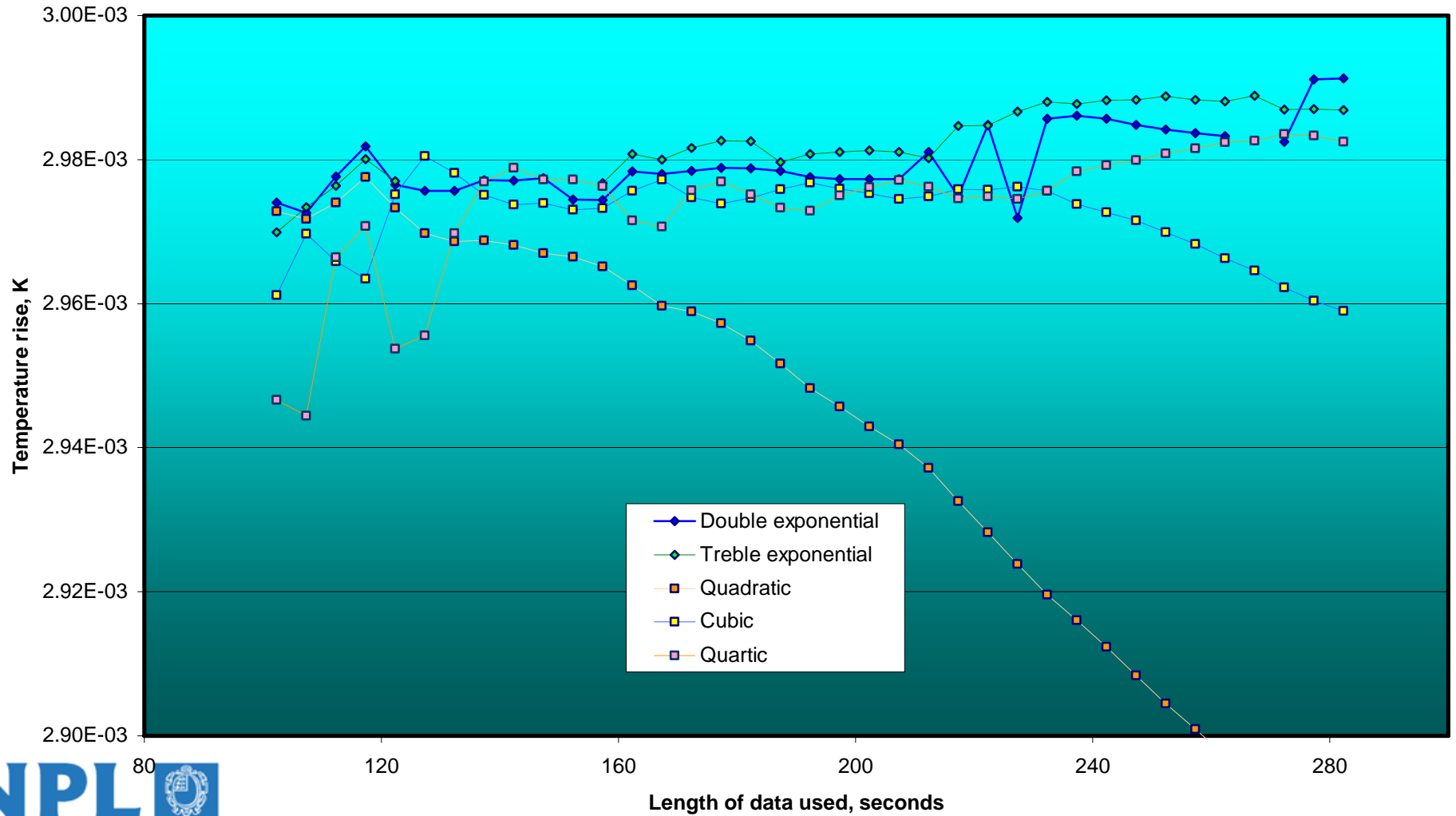
# Analysis: Results from real data

10 MeV, 15 Sept 06, Run 4



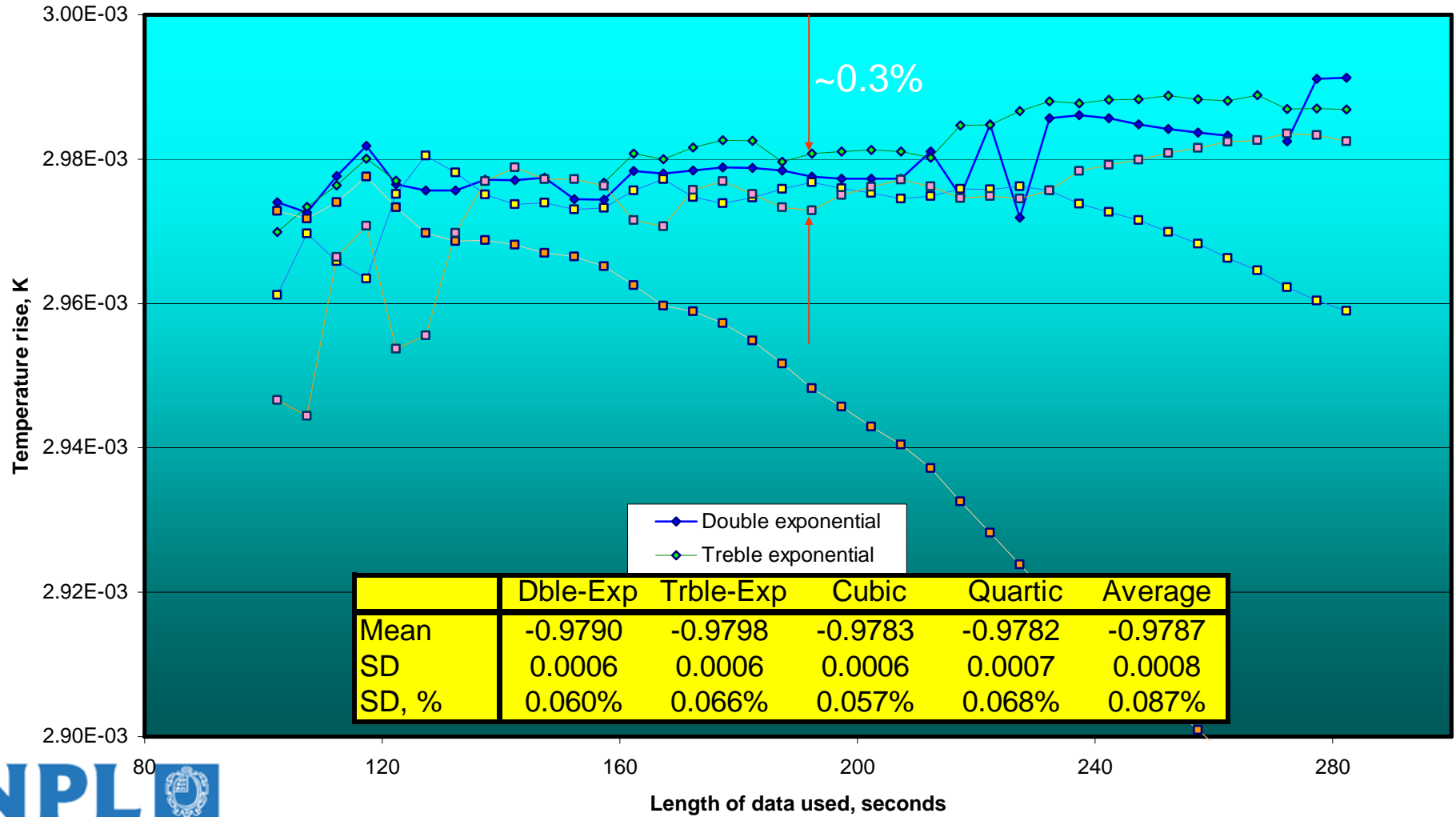
# More real data

10 MeV, 15 Sept 06, Run 10

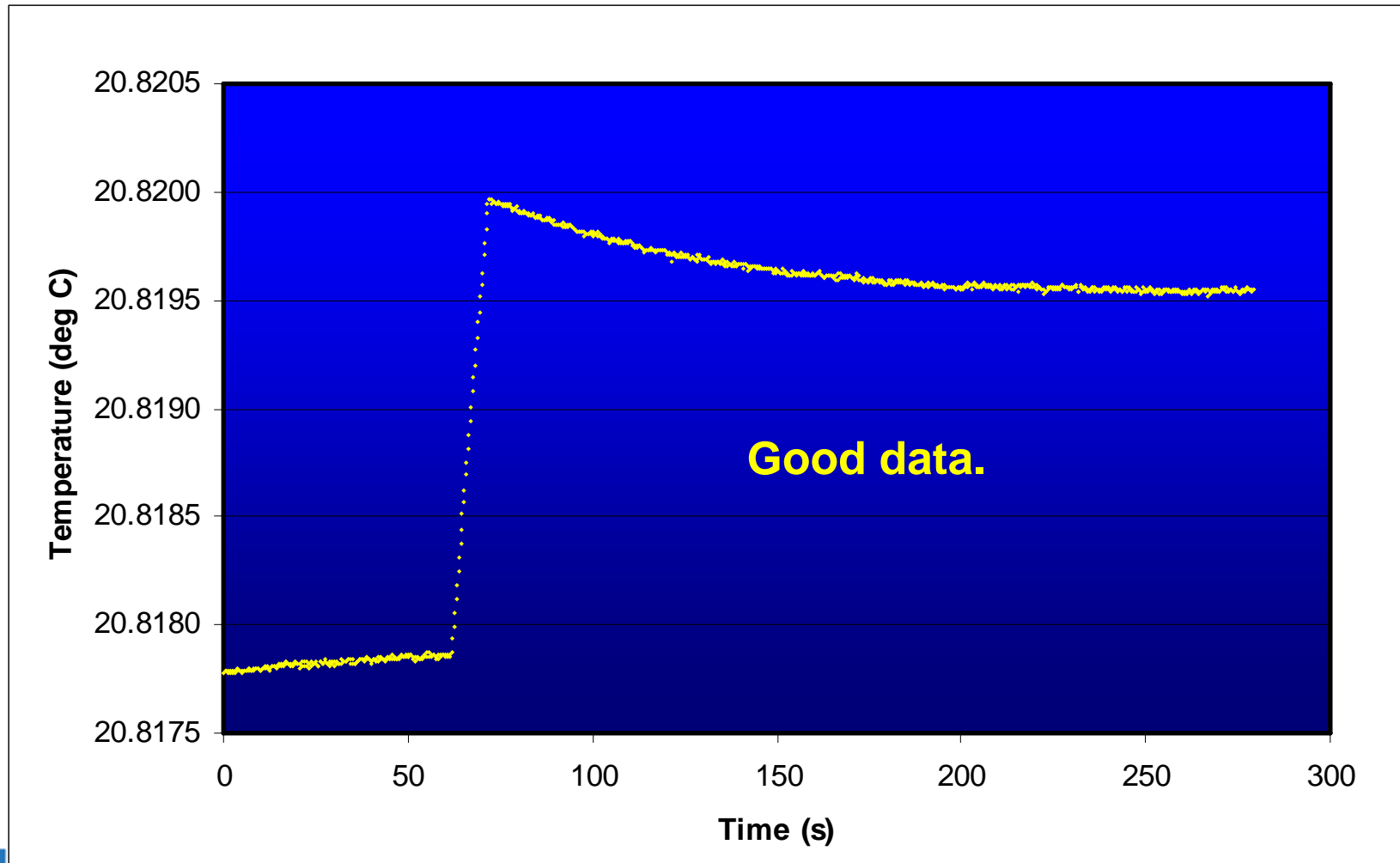


# More real data

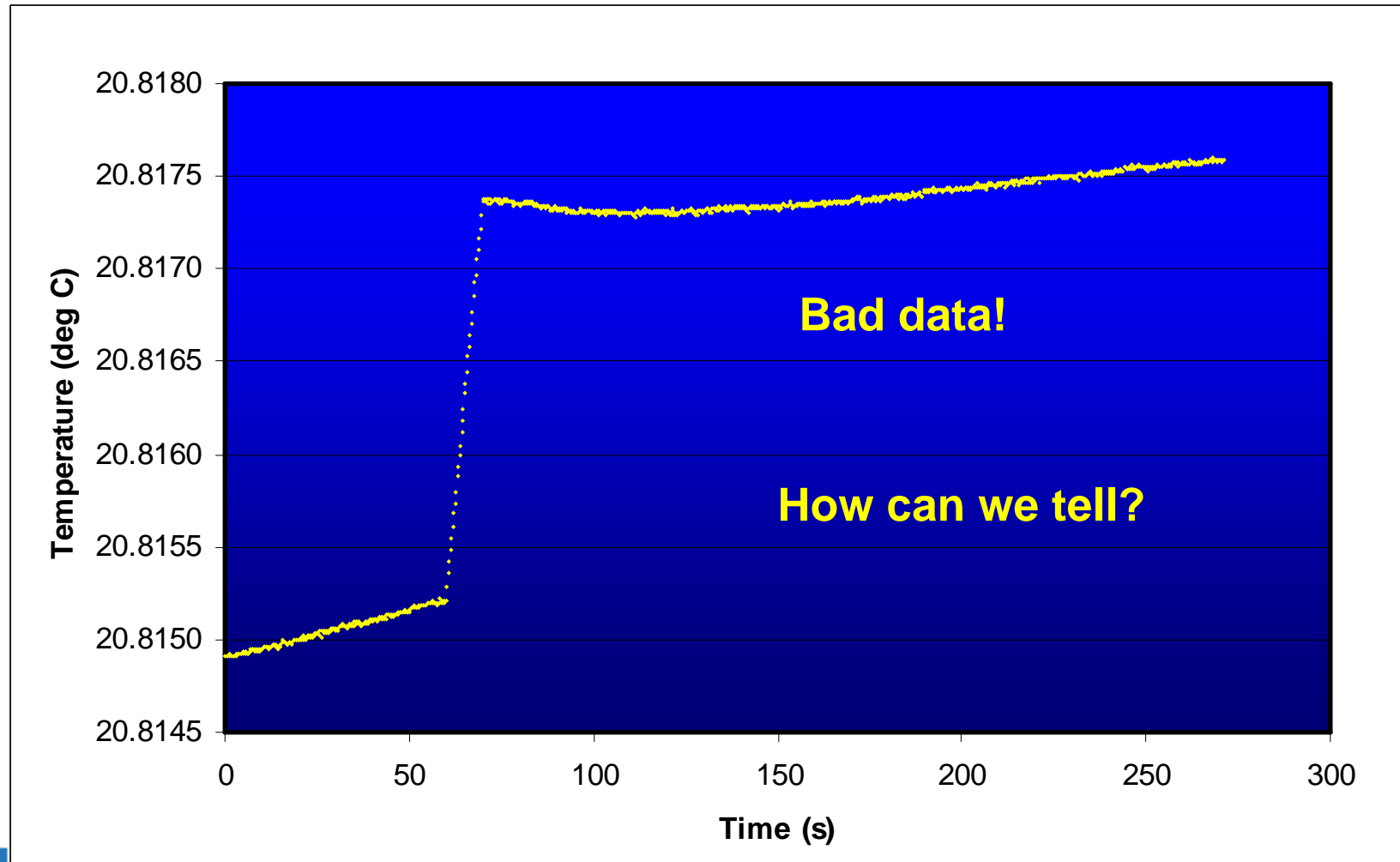
10 MeV, 15 Sept 06, Run 10



# The real data

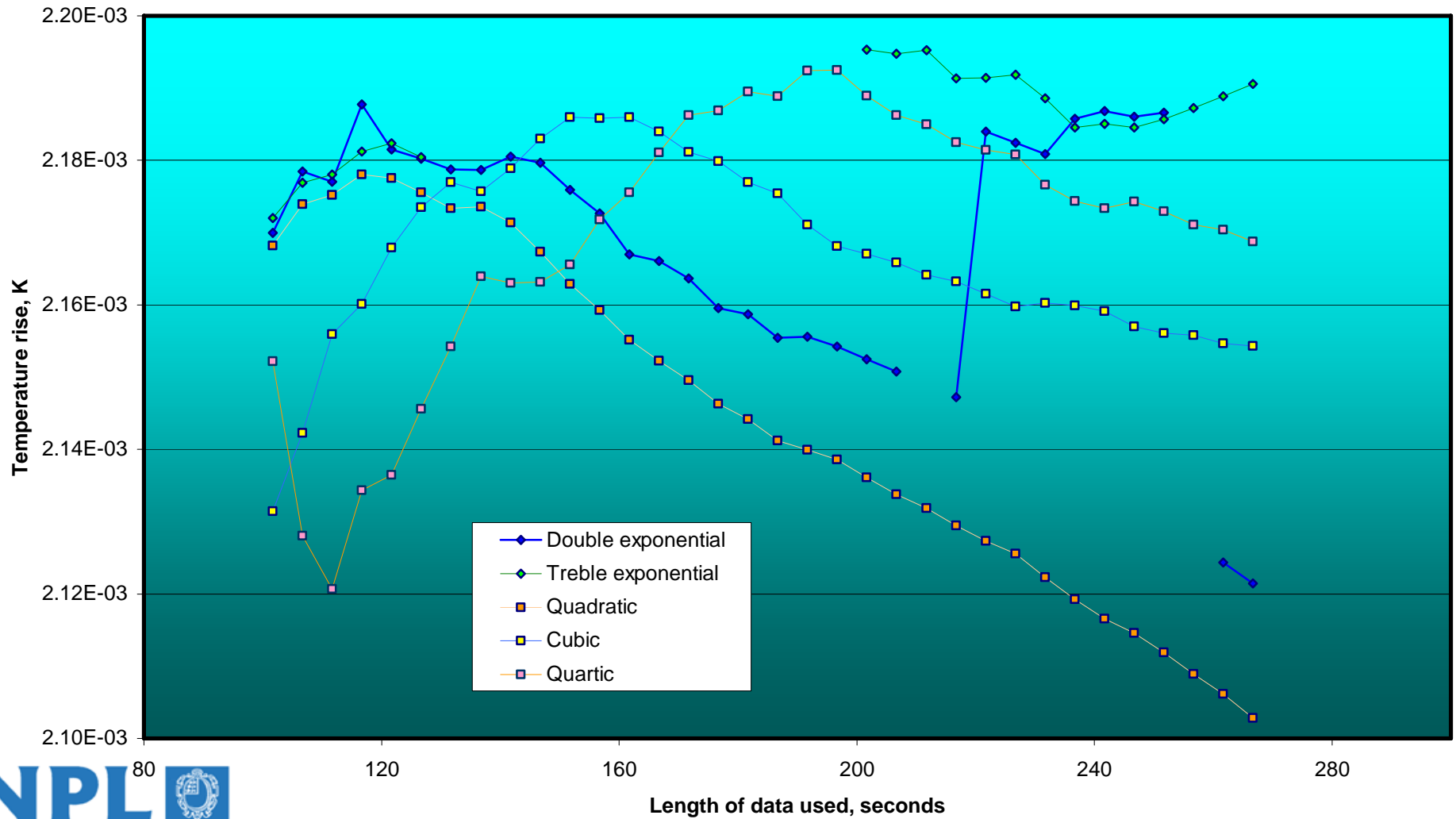


# The real data

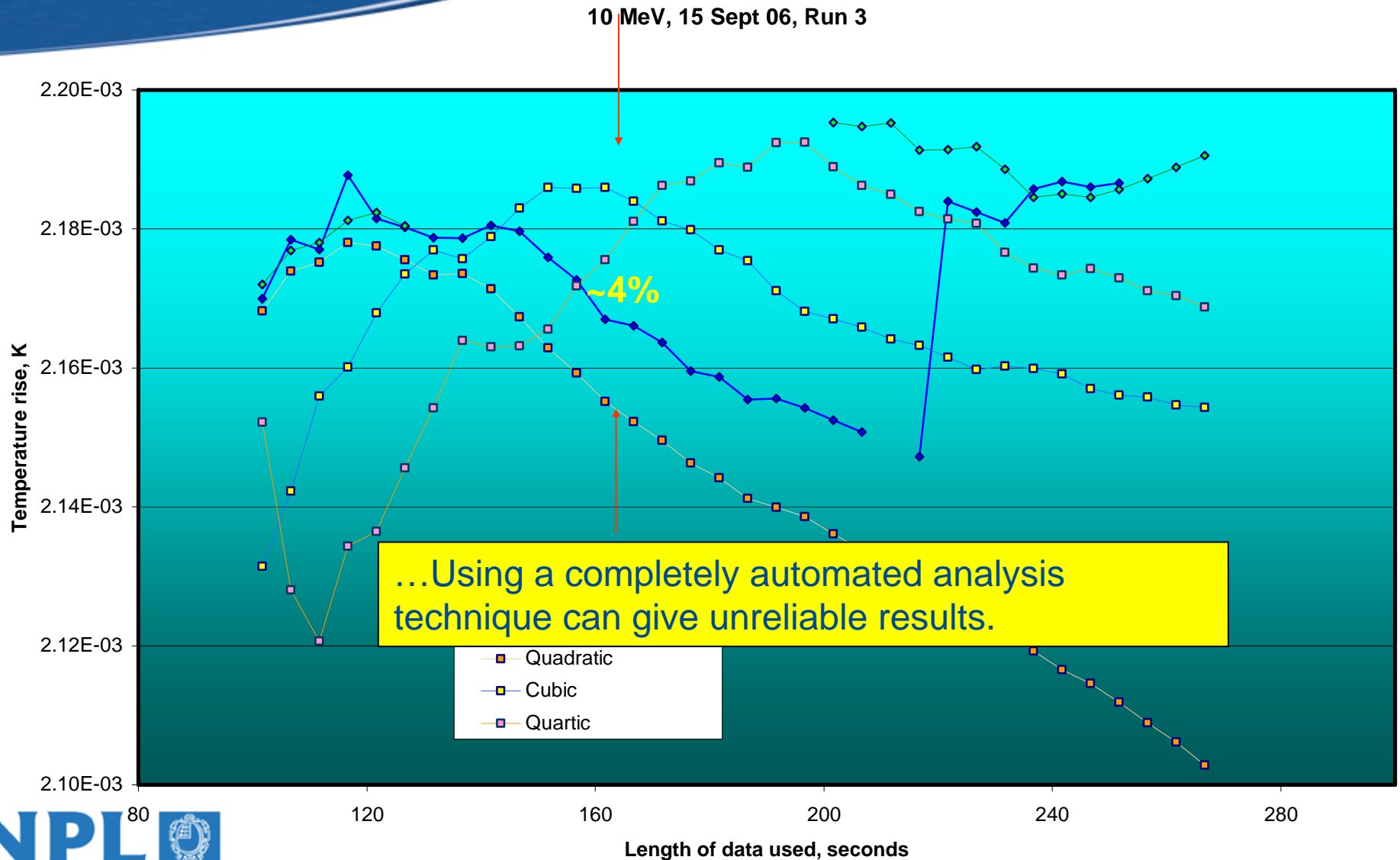


# Analysis: Results from bad data

10 MeV, 15 Sept 06, Run 3

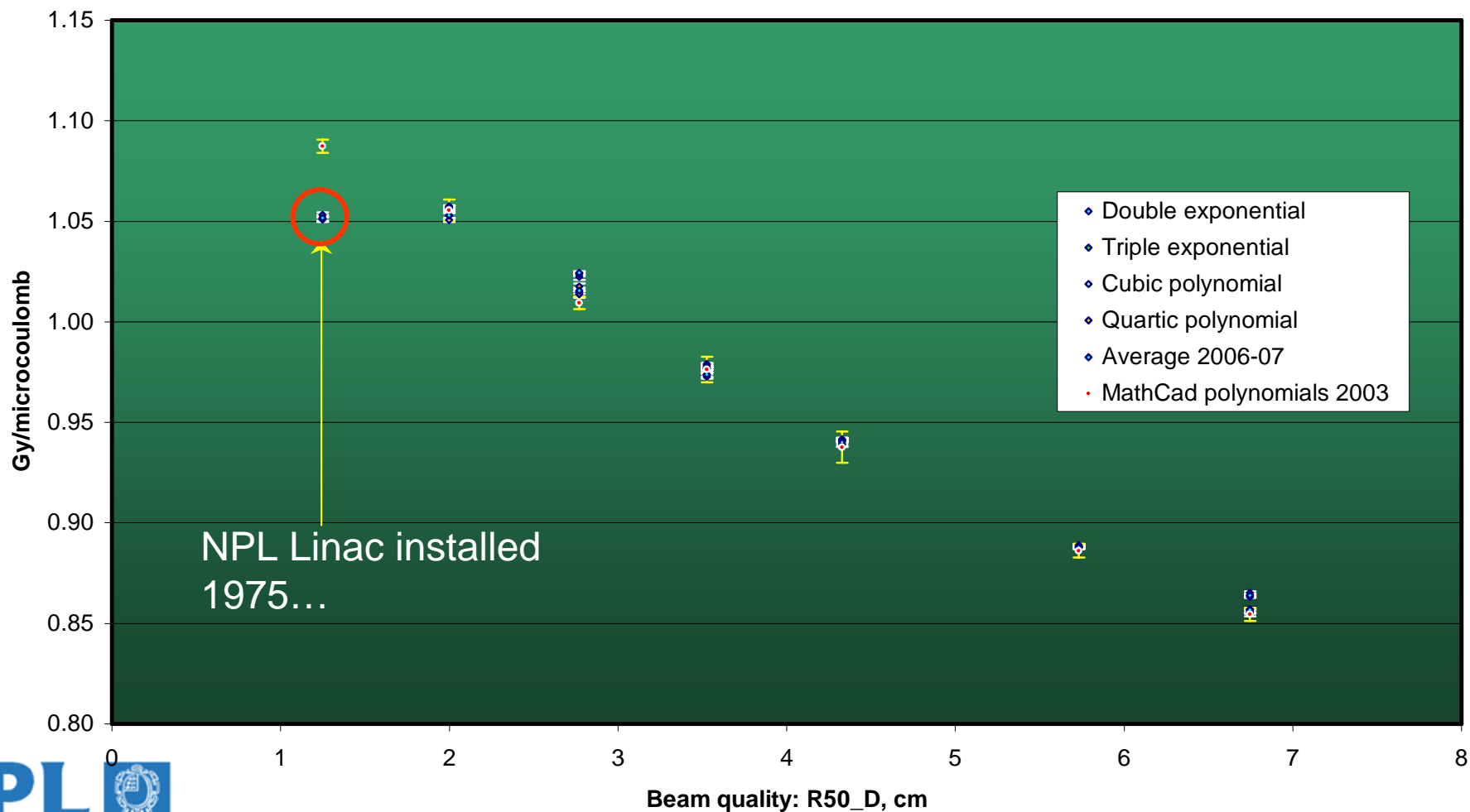


# Analysis: Results from bad data



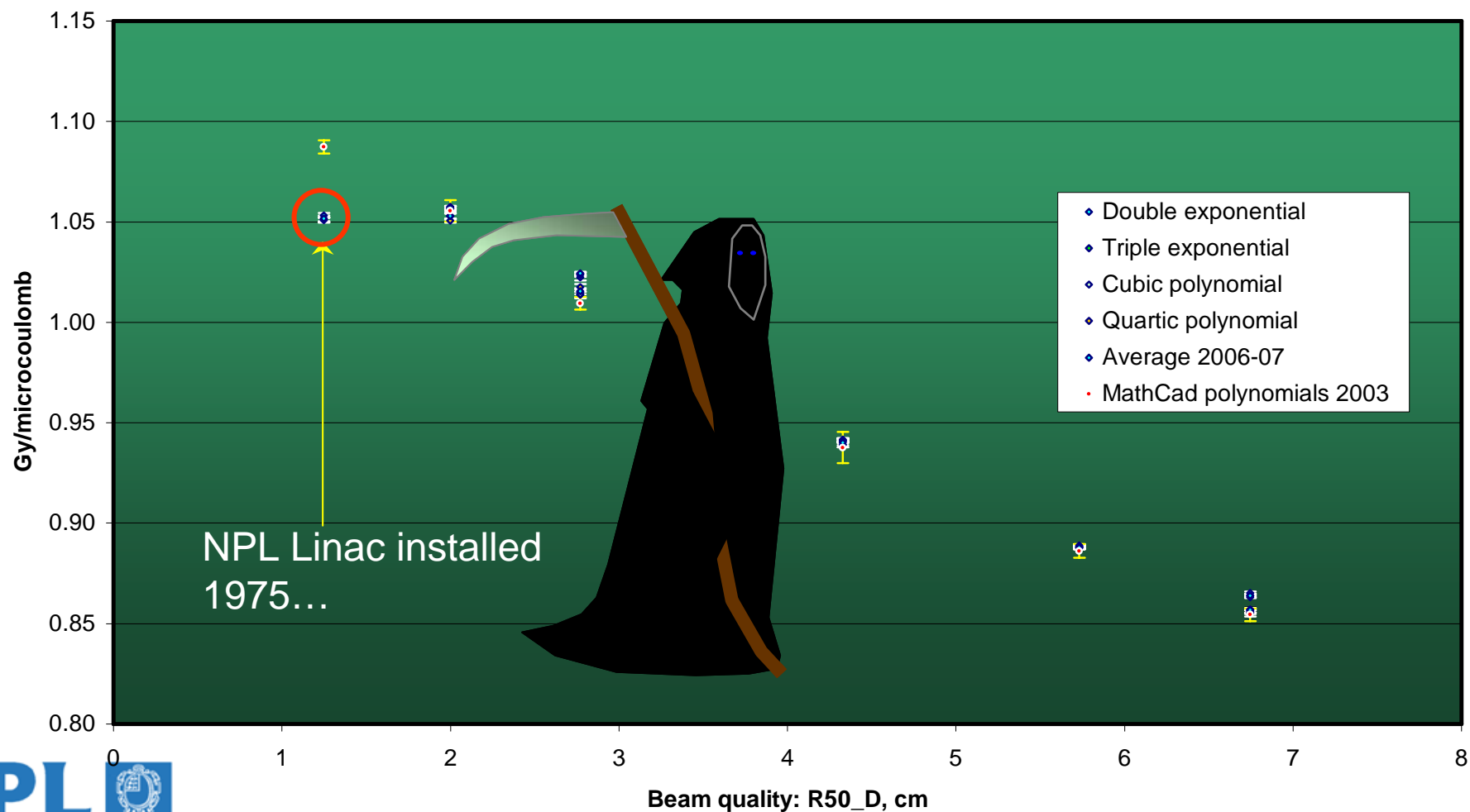
# Results: Refurbished and with new analysis method

Calorimeter/monitor ratios Sept 06 - Feb 07  
with normalised 2003 data



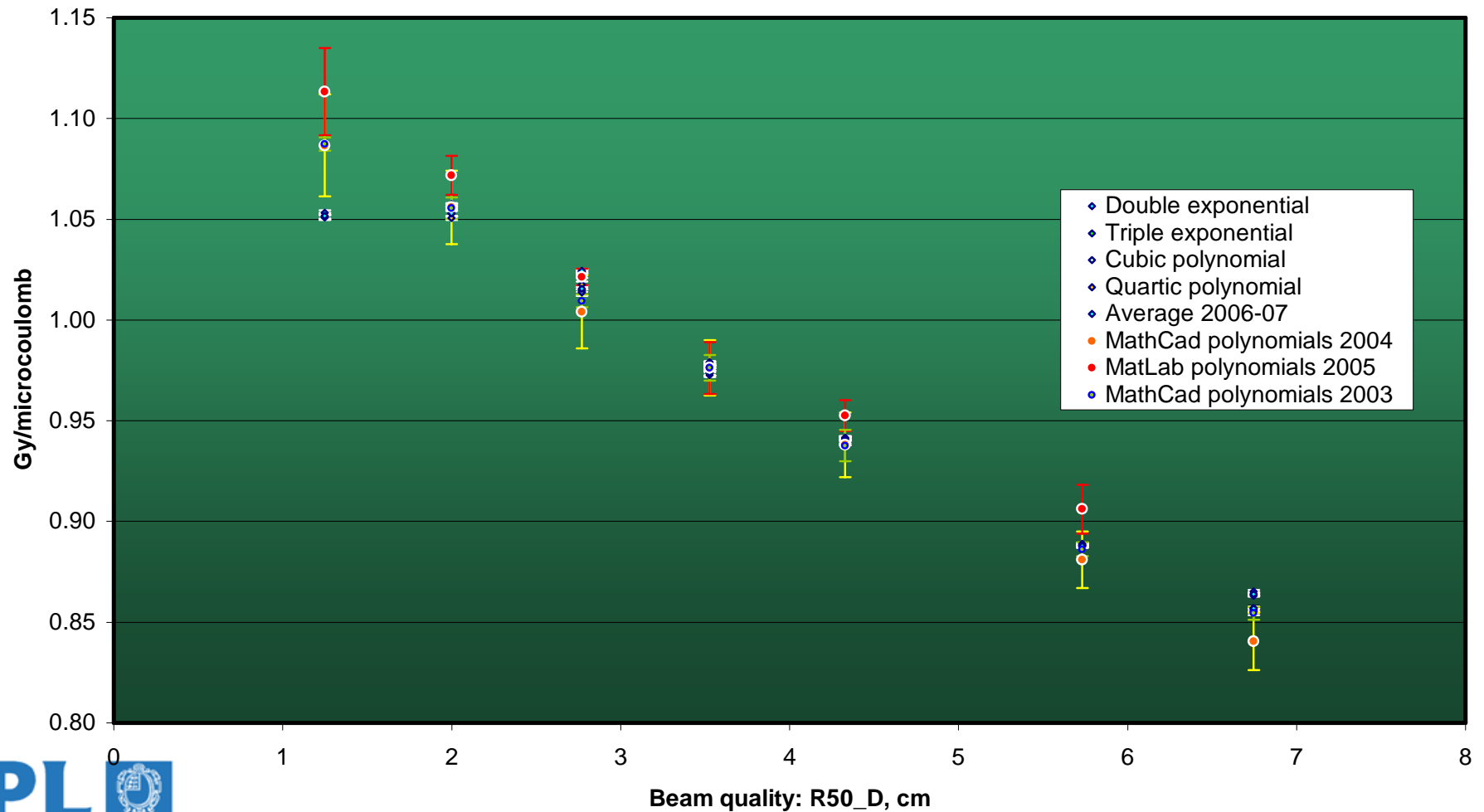
# Results: Refurbished and with new analysis method

Calorimeter/monitor ratios Sept 06 - Feb 07  
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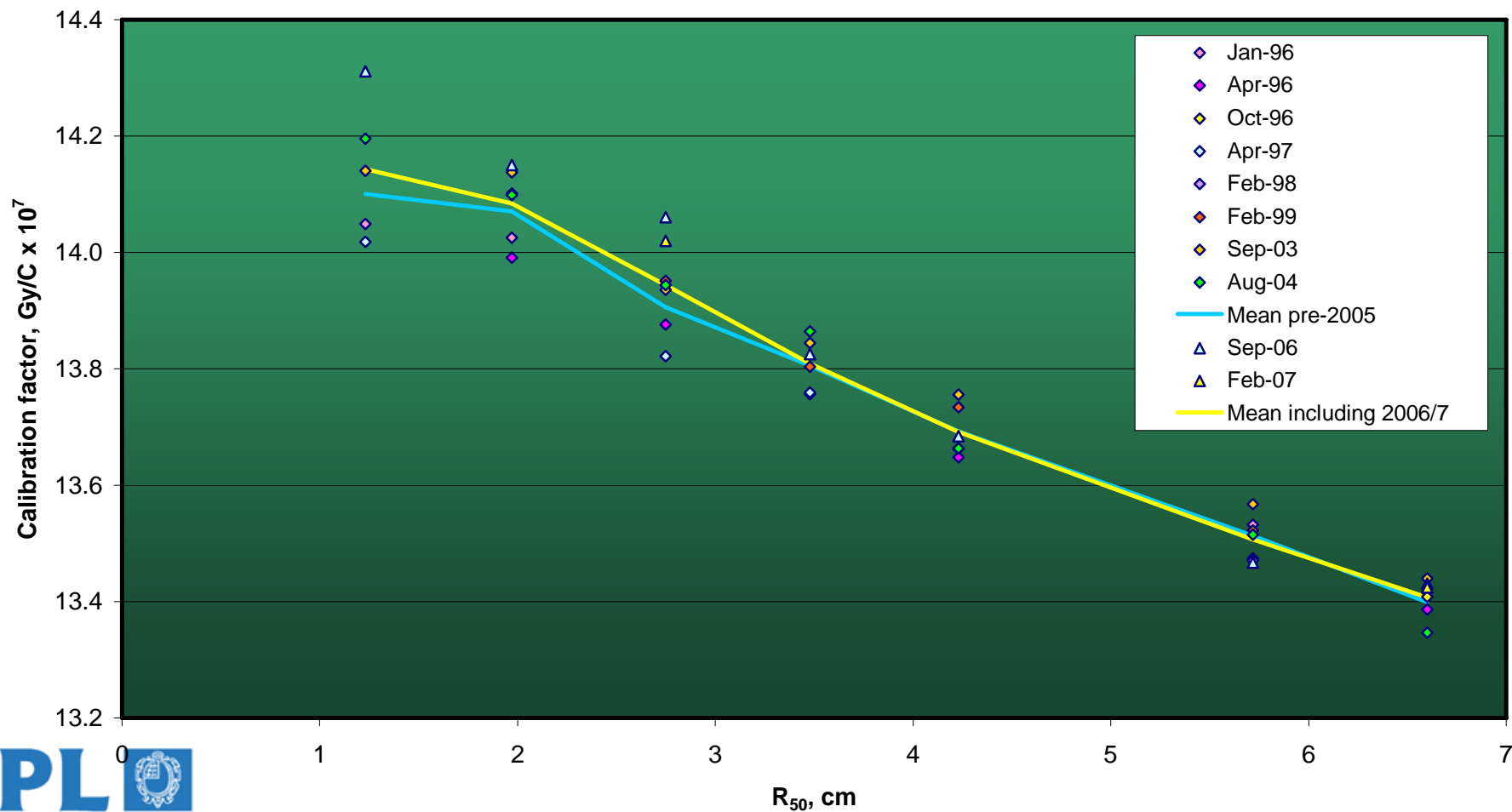
# Results compared with older data

Calorimeter/monitor ratios Sept 06 - Feb 07  
with normalised older data included



# Calibration of working standard NACP-02 chamber

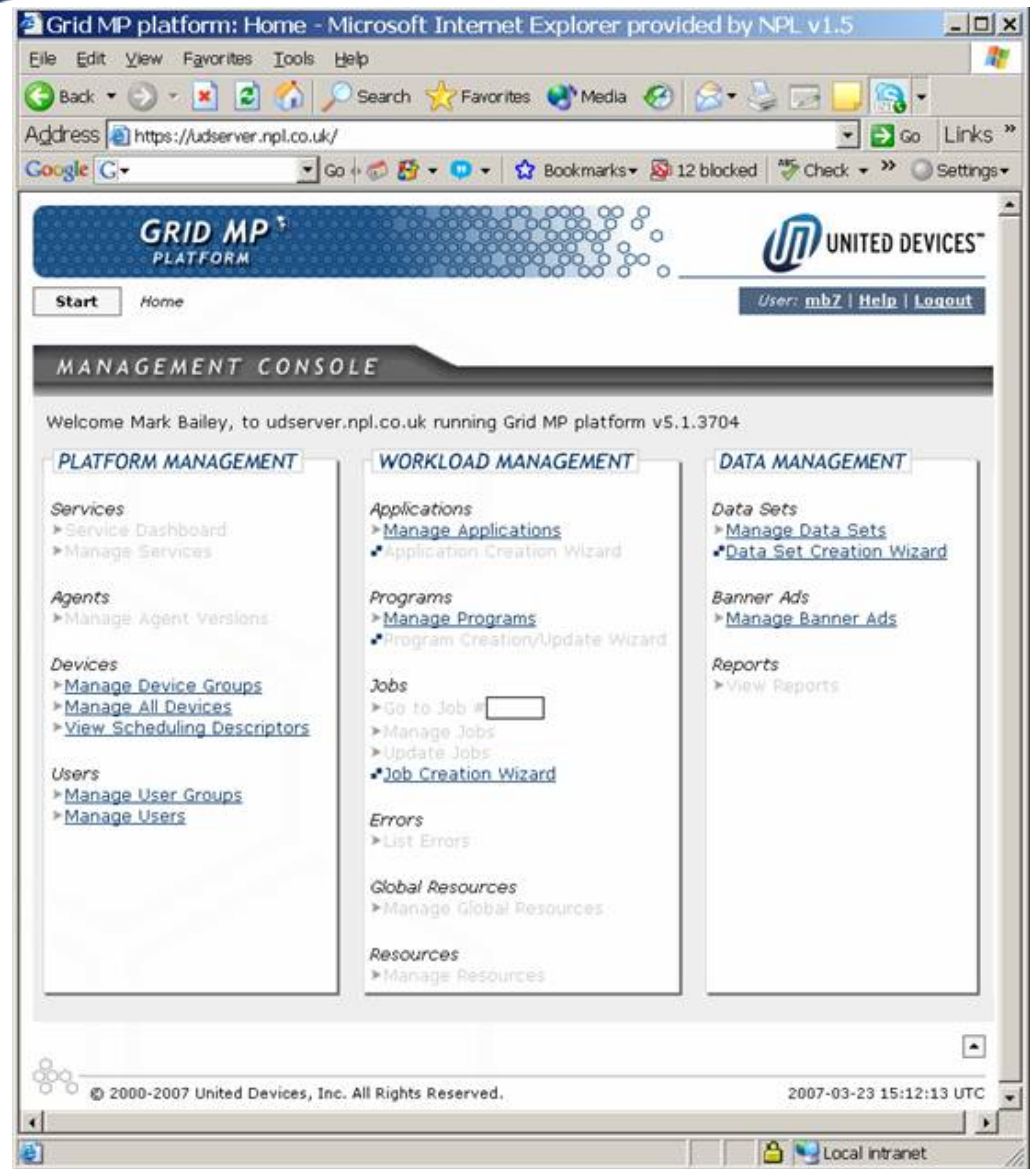
NPL NACP-02 Chamber 3009  
Including 2006 and 2007 data  
(2005 data excluded)



- The UK Primary Standard Electron Beam Therapy Level graphite calorimeter has been refurbished and improved
- Now delivers a smaller, measurable uncertainty in the calibration of NPL's transfer standard ionisation chambers
- Core support system and new electronics, are being adapted for inclusion in the new design for a replacement graphite calorimeter to be the UK Primary Standard for electron and photon beams
- Gap calculation techniques using EGSnrc user codes, on the UD Grid running on the NPL PC network, have been successfully trialled for the electron calorimeter and will be used for the new Primary Standard calorimeter...

# Gap effect uncertainty contribution

- Gap effect currently built in as unity correction with 0.17% (K=1) contribution to uncertainty
- Monte Carlo calculations done by E Kirby using NPL Grid in 2006, with DOSRZnrc
  - Large-scale test of NPL Grid of ~few hundred PCs
  - United Devices Grid software used
  - Scripts and GUI prepared by David Shipley



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The screenshot shows the 'NPL UD Grid client' window. It features a menu bar with 'File'. The main interface includes several input fields and buttons:

- Start seed:** 1, **End seed:** 10
- Select template file ...:** 6.85Mev\_z3phsp.egsinp, **Generate Seeds** button
- Username:** [empty], **Password:** [empty]
- Program name:** DOSRZnrc\_BEAMsrc (dropdown),  Use Test Grid, **Submit Job** button
- Job ID:** <id>, **Get Job Status** button
- Get Job Results** button
- Delete Job** button
- Select module ...:** mp\_dosrznrc-CLINAC2300-src.exe, **Prepare Job Data** button
- Select executable ...:** <executable>, **Merge Job Data** button

A text area at the bottom displays the following output:

```
GenerateSeeds.pl 1 10 6.85Mev_z3phsp.egsinp
Clearing directory...OK
Creating seed files... 10 seed files created OK.
```

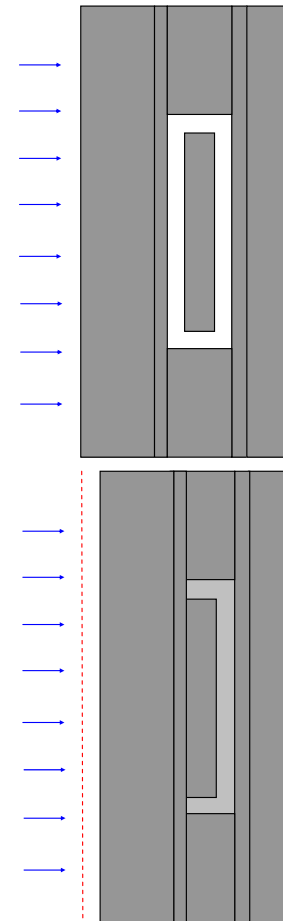
The version 'gridClient: v0.35' is shown at the bottom left, and an **Exit** button is at the bottom right.

## Gap effect calculation (continued)

- Calculations performed to calculate effect of gaps
- Compensated gap calculations carried out
- $\sim 8 \times 10^9$  histories
- Several weeks' CPU time compressed into a few hours

Nominal beam energy, MeV	$R_{50,D}$ cm	Difference, %	Uncertainty, %
4	1.23	-0.31	0.34
10	3.48	0.30	0.08
19	6.6	0.29	0.04

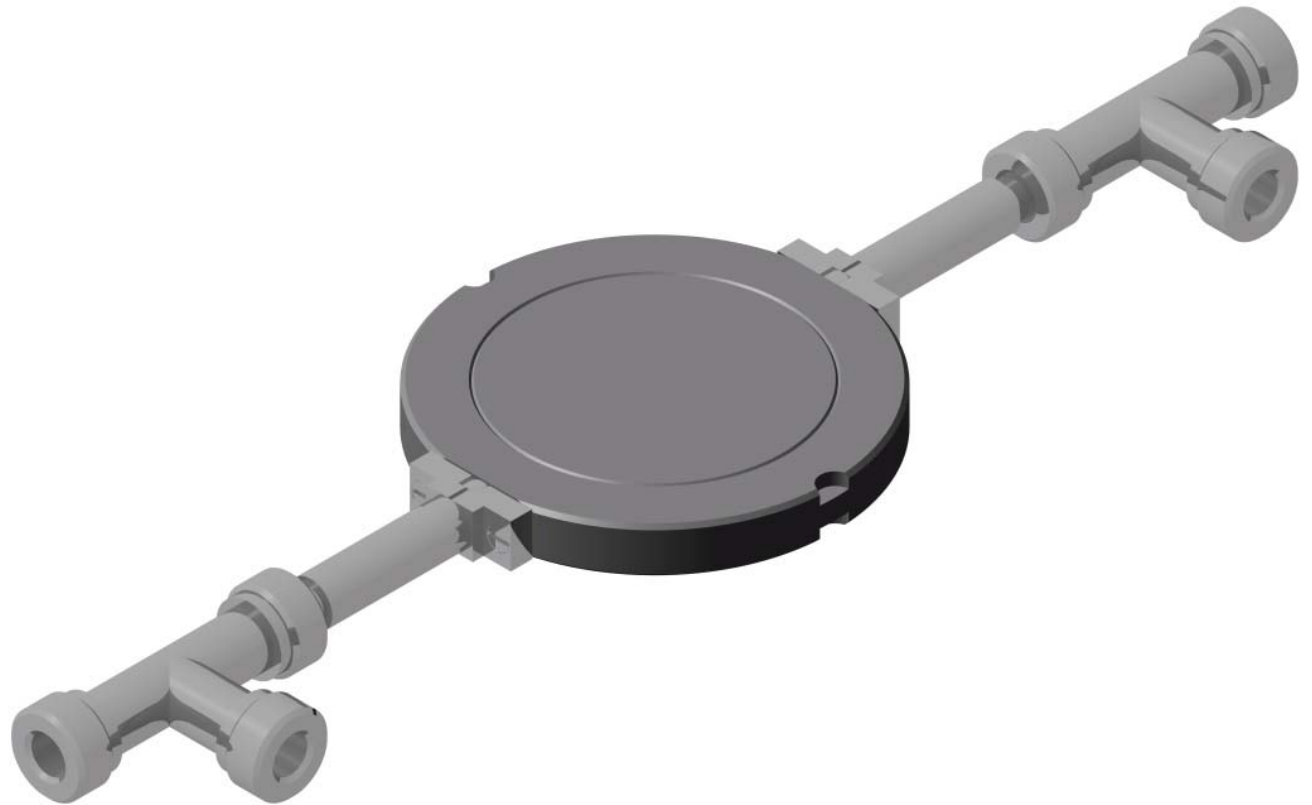
- Results consistent with built-in uncertainty
- EGSnrc/DOSRZnrc/egspp Monte Carlo codes, with the NPL Grid, being used in design of NPL's new electron and photon primary standard absorbed dose graphite calorimeter



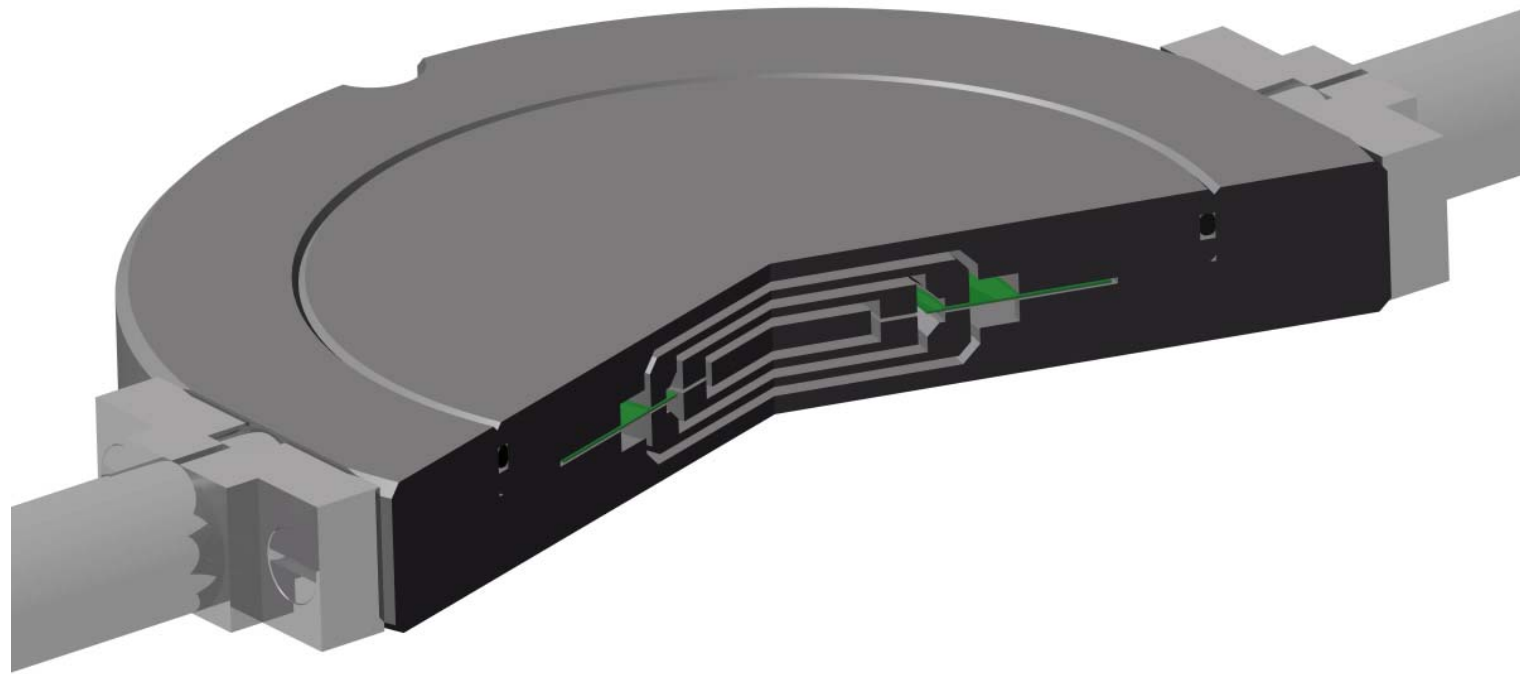
# Replacement electron/photon calorimeter

- NPL Currently building a new graphite calorimeter to replace the ageing photon microcalorimeter and electron calorimeter
- Designed to operate chiefly at therapy levels
- Incorporating design ideas from LNHB's GR8 and GR9 calorimeters as well as improvements in electronics from the current electron calorimeter
- Core, first jacket ("shield") and second jacket ("mantle") will be operated at constant temperature, with DC or switched DC Wheatstone bridge networks maintained close to balance
  - Experience with AC bridges and control systems strongly influenced this decision!

# New calorimeter illustrations



# New calorimeter illustrations



# New calorimeter illustrations

