Absolute Calibrations:
Sign Toggling and *Fringe Fitting*

Presented by
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Outline of Talk

- Objective of Investigation
  - » Calibration of Input−Test−Masses (ITMs)
  - » Desired amplitude accuracy
- Three approaches:
  - » Fringe Counting
  - » Fringe Fitting
  - » Sign Toggling
- Results and next step

Objective

```
(10V/2^16cnt) * (3V/V) * (7.2kOhm/570Ohm) *
 (4 * 16mN/A)/(1200V/A) * 1/(10.3kg (2*pi*740mHz)^2) =
 = 1.4 [nm/cnt]
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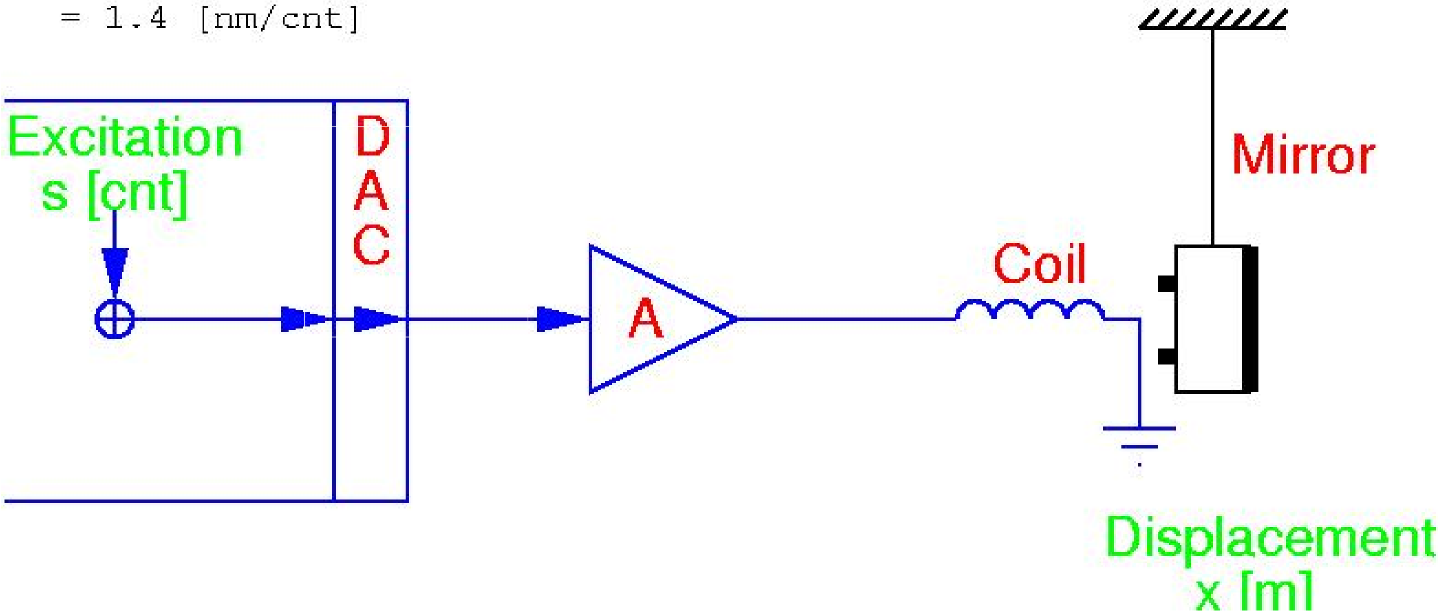
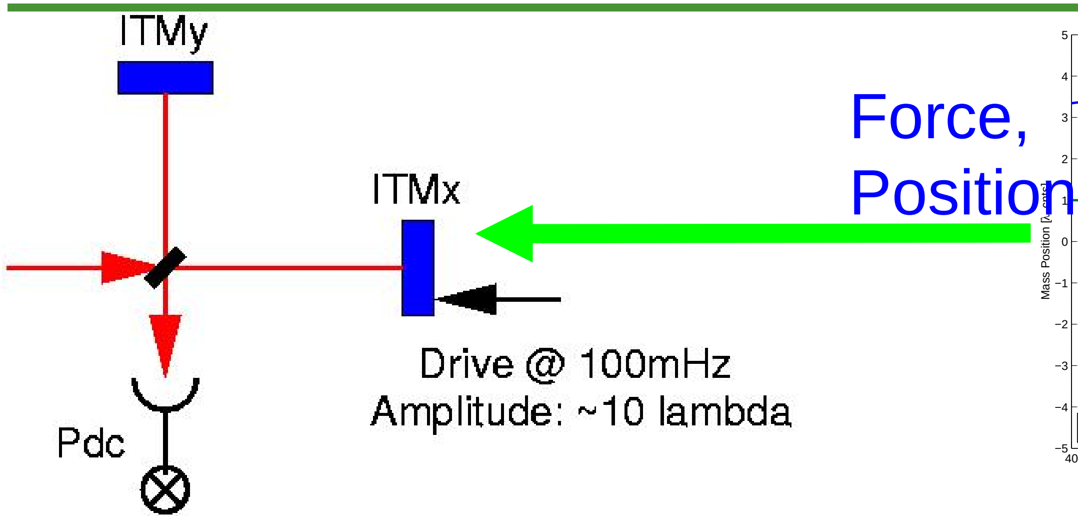
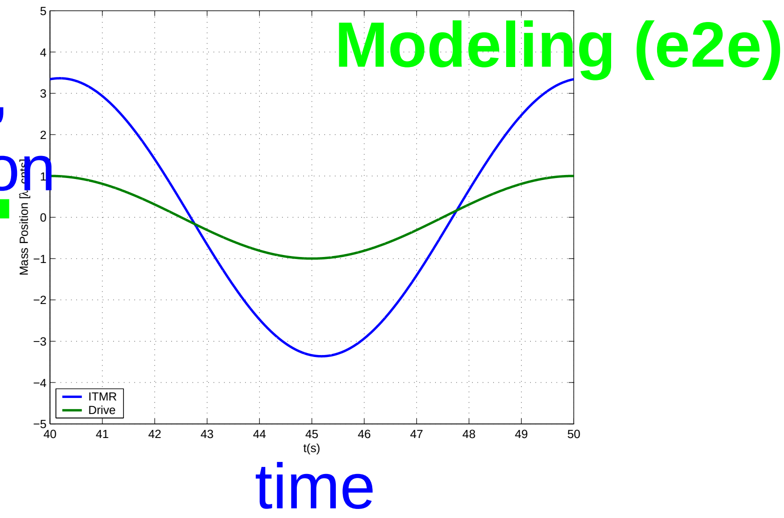
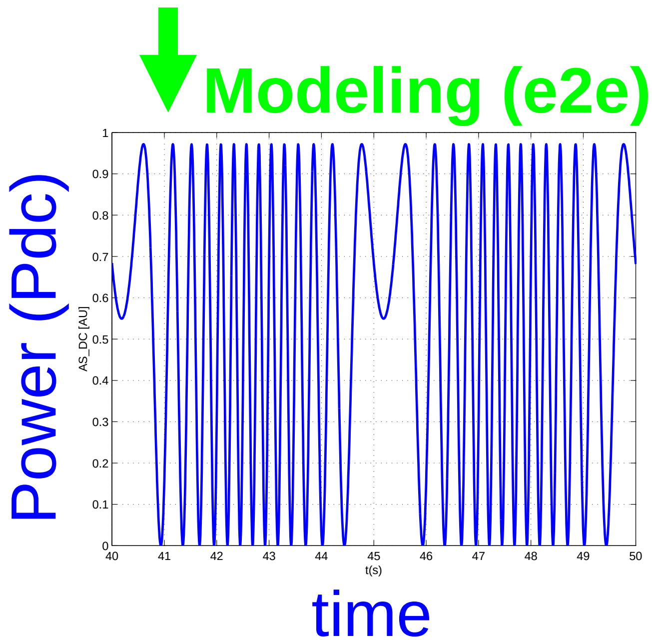


- Calibrate drive with respect to the laser wavelength
- Expected: 1.4 nm/cnt
- Aim for <5% accuracy
  - » assume 1−10 events with SNR 10−100, the physical results should not be limited by the systematic uncertainty of the calibration
    - – see Sigg, D. LIGO−T970101−1, Shutz B., *Nature*, **323** 310 (1986), ...

And how? Fringe Counting



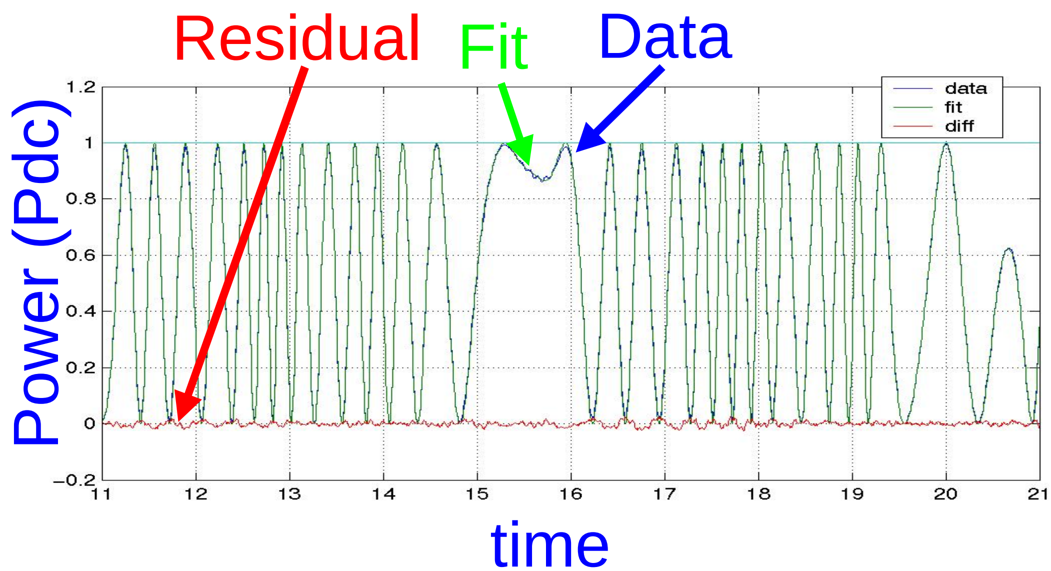




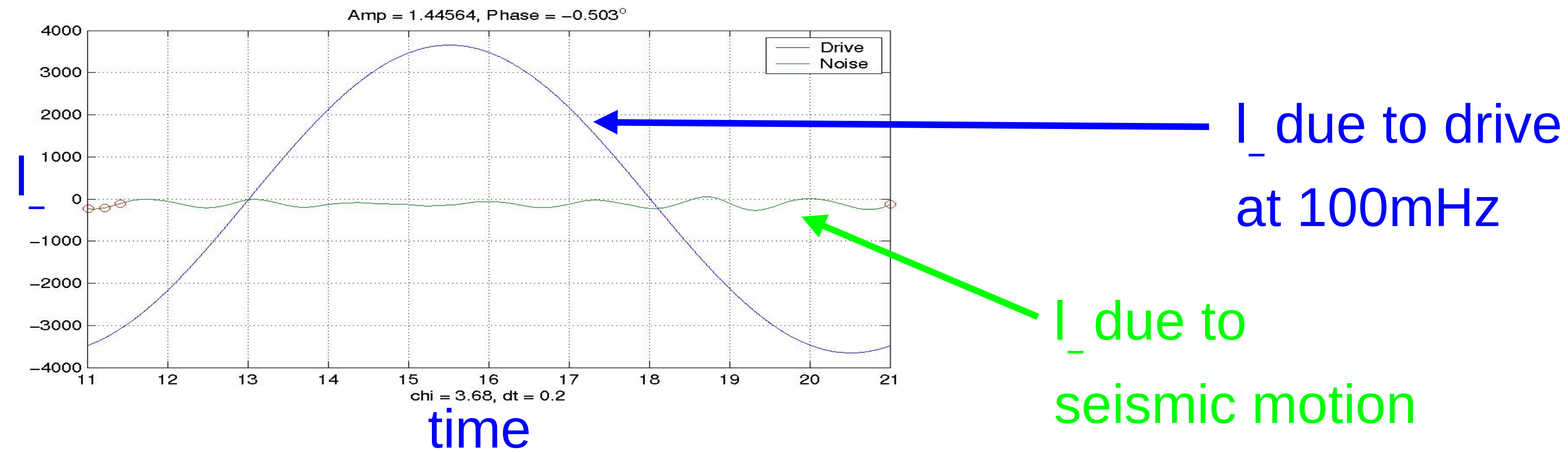
- Drive @ 100mHz, ~5*λ_{pp} amplitude
- Calibrate by counting fringes and dividing by the applied control signal
- Well suited for quick 5−10% accuracy
- <5%: mechanical TF (mag & phase) needs to be taken into account

Inelegant

LIGO *Alternative to Fringe Counting: Fringe Fitting*

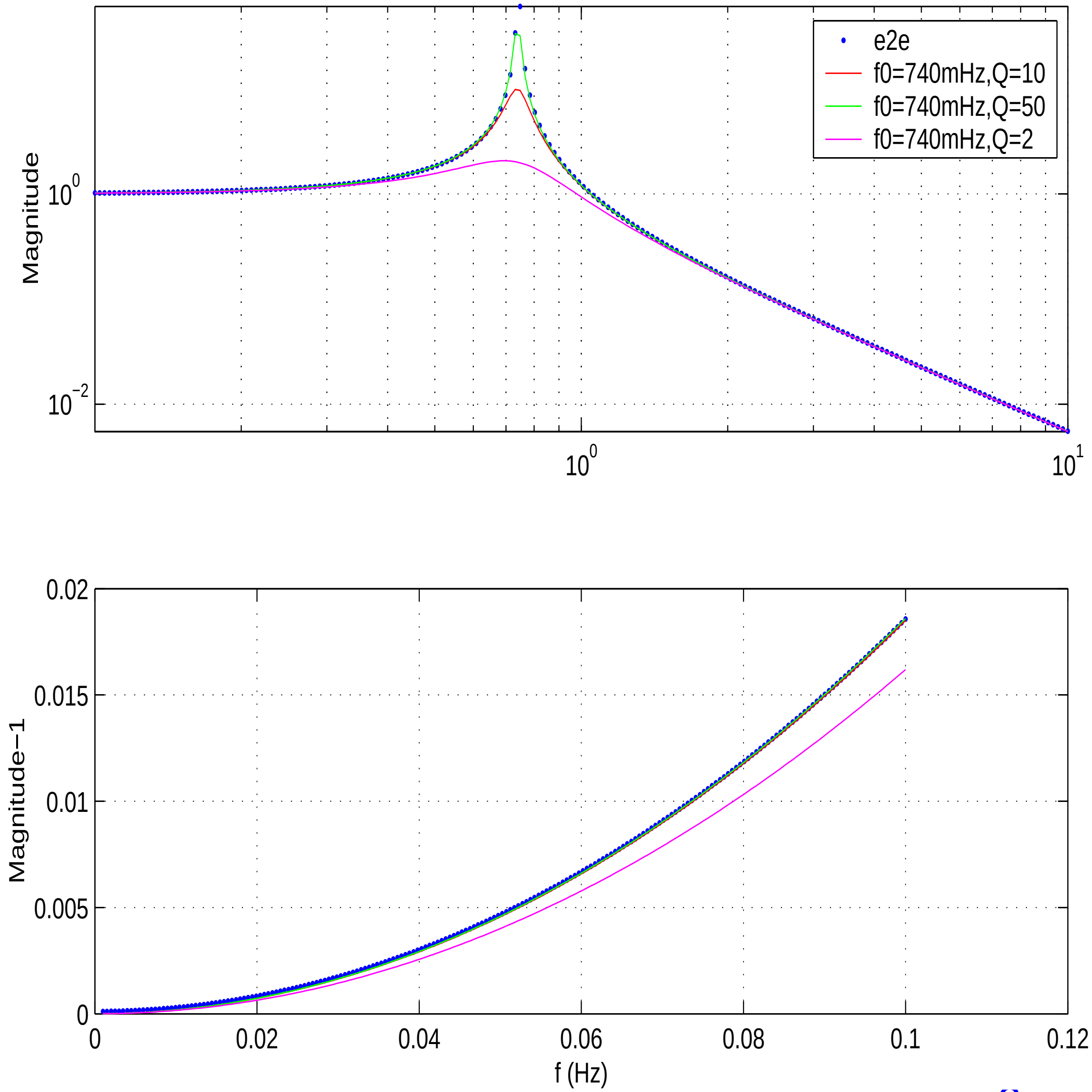


- *Fringe Count* data fit
  - » Pdc = A * sin(l_ * t) + n
    - – l_ (Michelson length change due to drive, seismic motion,...)
    - – n (electronic noise)
  - » Calibration of drive by searching for 100mHz line

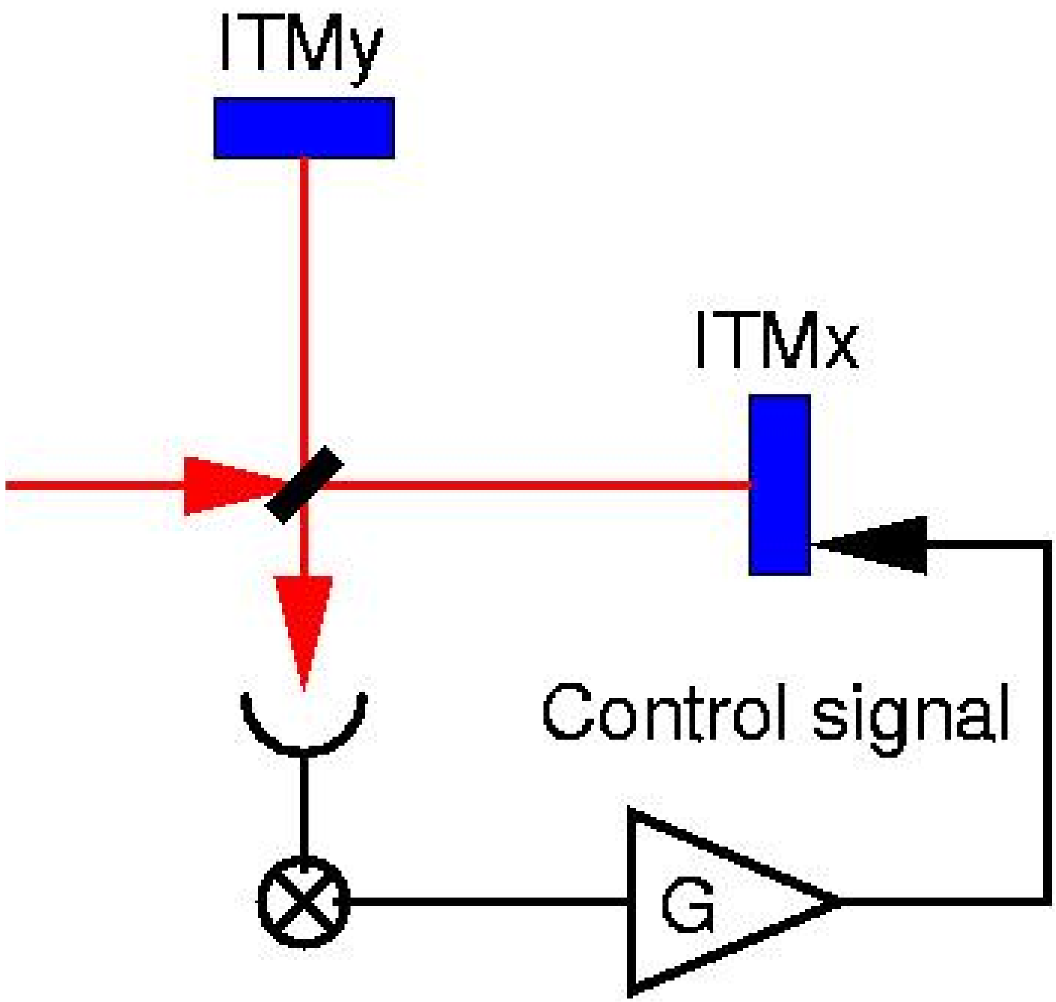


Analyzing Fringe Fitting results

- Fringe Fitting
  - » Range: ~5*λ peak−peak
  - » Offsets do not play a role
  - » Mirror phase lag does not cause a problem
  - » DC extrapolation
    - – need to correct for 1.8% calibration overestimate (Q=2−50)



Different approach: Sign Toggling

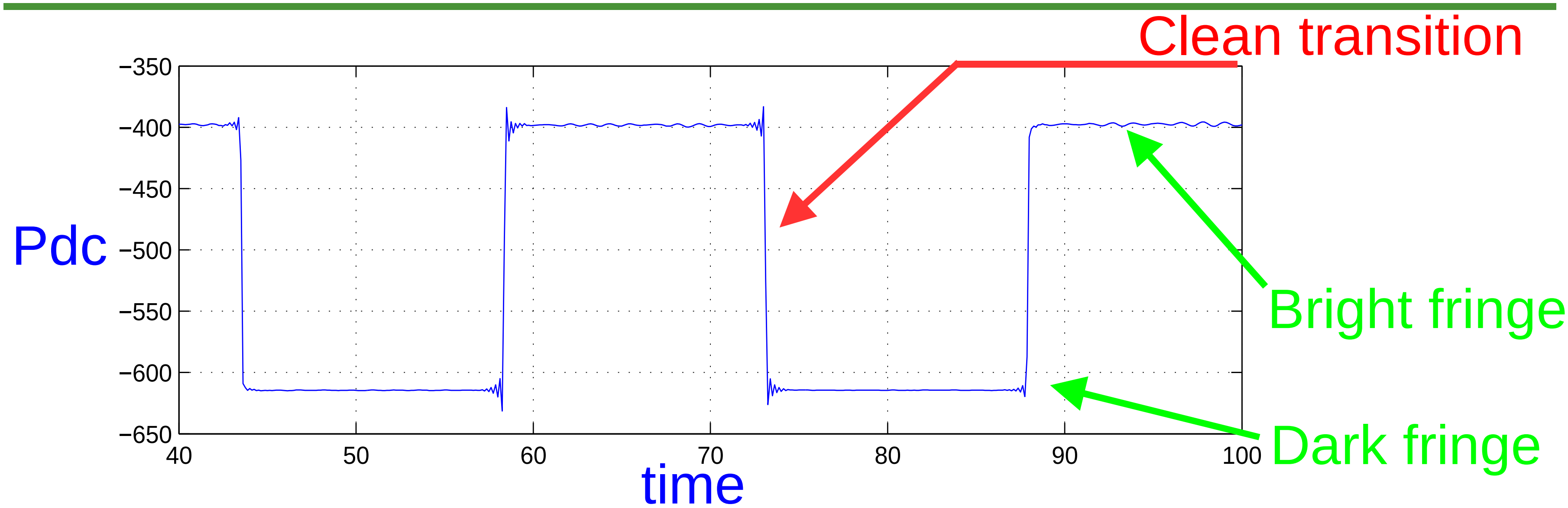


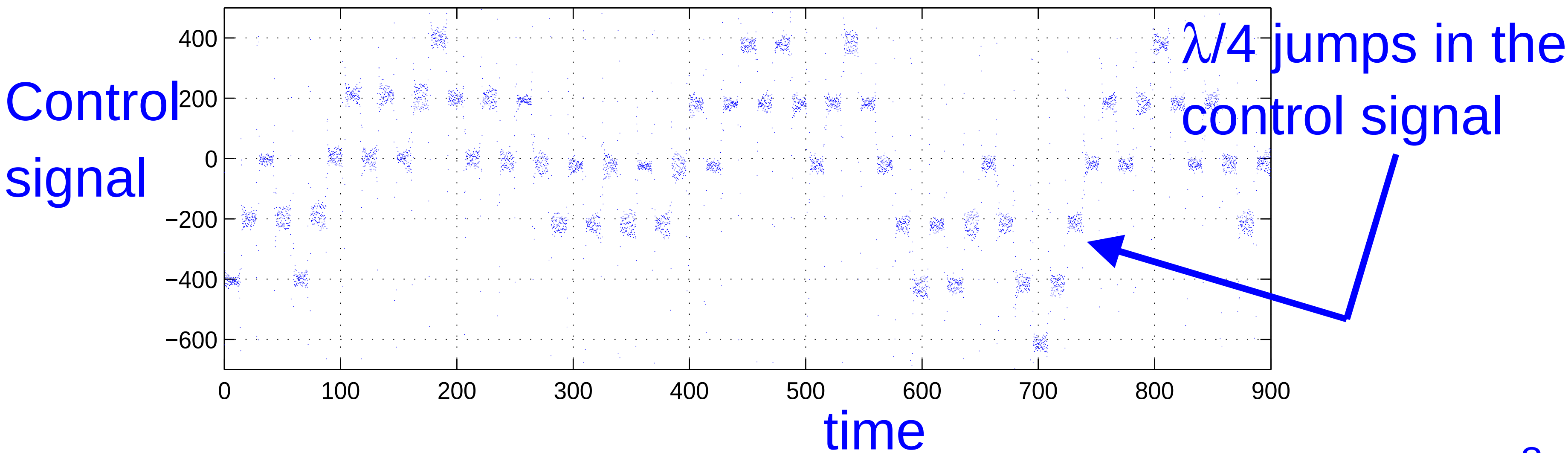
1. Lock Michelson on dark/bright fringe
2. Wait N seconds
3. G−>−G, Michelson transitions to bright/dark fringe
4. Goto step 2

$\lambda/4$ transition

Calibration of control signal

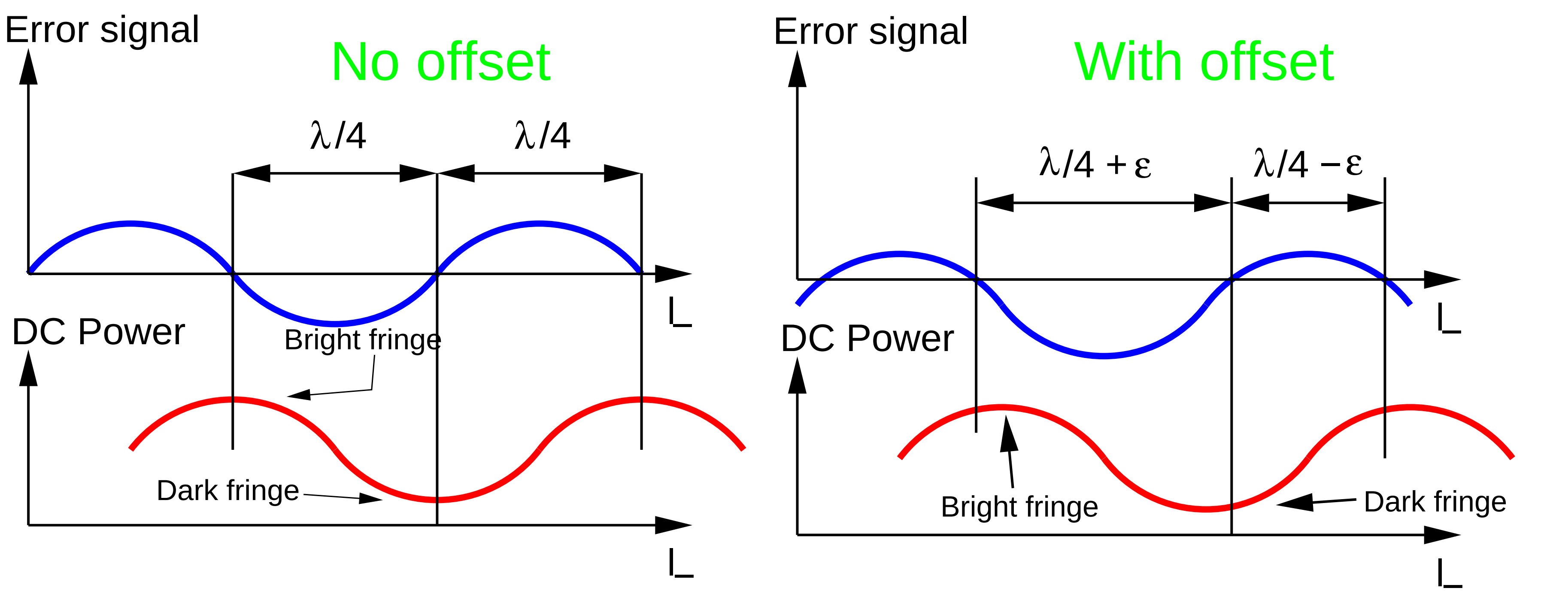
IFO data (4k LHO): λ/4 jumps



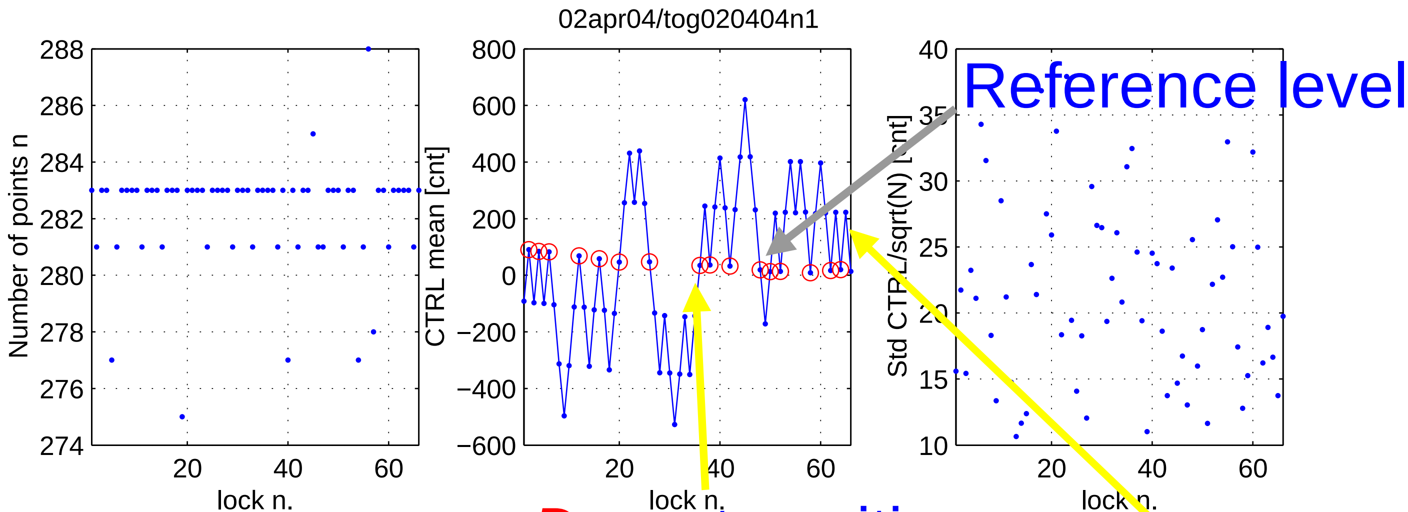


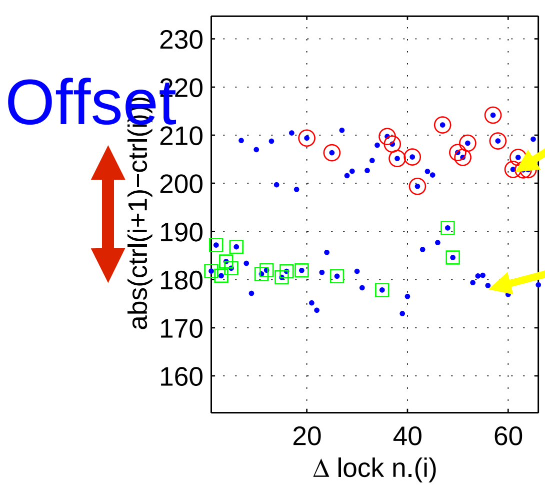
Analyzing Sign Toggling results

- Sign Toggling
  - » Range: $\lambda/2$
  - » Correct for calibration underestimate of 6% due to notch filter
  - » Approach is sensitive to offsets: take sum of $\lambda/4$ UP and $\lambda/4$ DOWN transitions
  - » Settling time: servo's time constants
  - » Gain requirements: 1/gain << 1% if 1% accuracy is desired



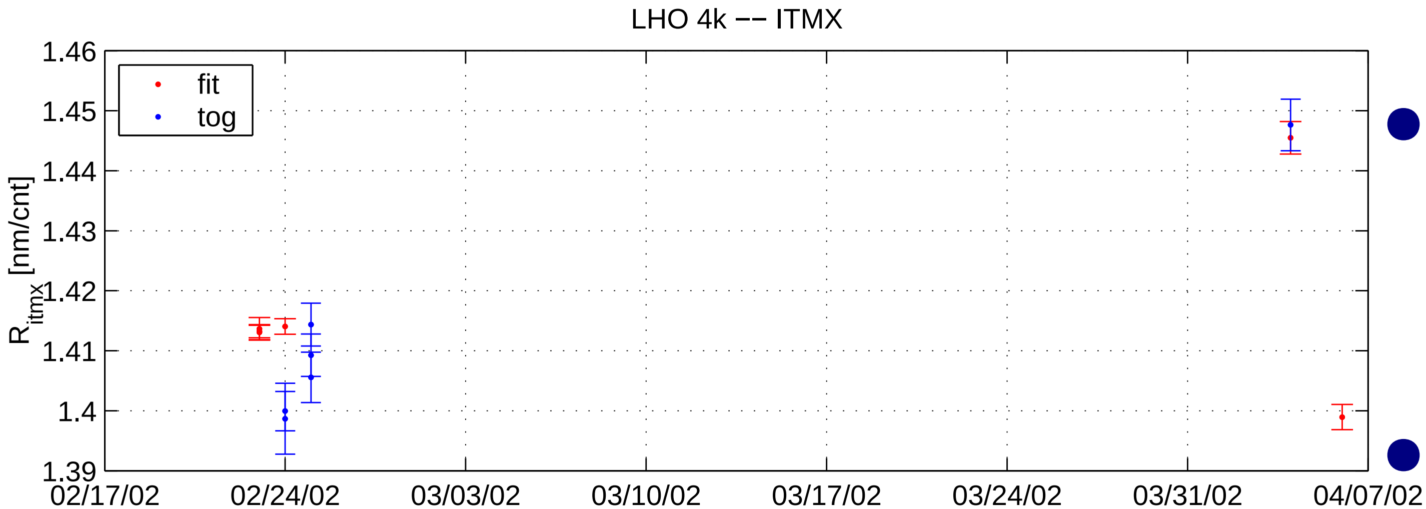
Sign Toggling Algorithm

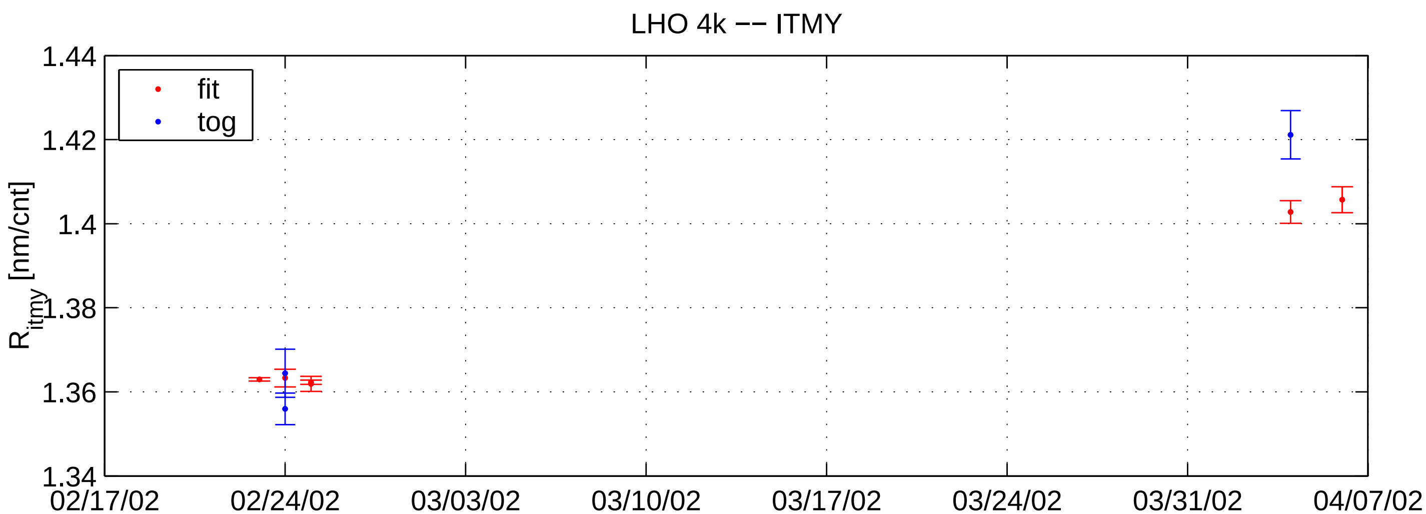





```
R_all [m/cnt] = 1.3771e-09 +- 1.1488e-11 (0.8%)
R_sum [m/cnt] = 1.3657e-09 +- 4.2894e-12 (0.3%)
R_wei [m/cnt] = 1.367e-09 +- 3.3519e-11 (2%)
Ncal=66 acal=193.1641 scal=13.092 zcal=1.6115
Ncal_up=17 acal_up=206.6353 scal_up=3.6804 zcal_up=
     mcal_up=206.3792 ecal_up=6.2233
Ncal_down=15 acal_down=182.9194 scal_down=3.241 zca
     mcal_down=182.7819 ecal_down=7.2331
Ncal_sum=32 mcal_sum=389.1611 ecal_sum=9.5419
acal_sum=389.5548 scal_sum=4.904 zcal_sum=1.2235
```

ITM's Absolute Calibration: Results





- Reproducibility of either approach ~1%
- Agreement between approaches:

  1−2%

Conclusions and Comments

- We presented two calibration approaches:

  Sign Toggling and *Fringe Fitting*
- Investigated different systematic contributions
  - » Offsets
  - » Mechanical TF: displacement/force (phase lag and 2% correction)
  - » Gain requirements
  - » Time constants of servo system
  - » Filters (6% correction due to notch)
- Promising results
  - » two different calibration methods agree to 1−2%
- Modeling (e2e) played a key role in the analysis
- Next steps
  - » propagate calibration factors to higher frequencies
  - » propagate ITM calibrations to End−Test−Masses (ETMs)