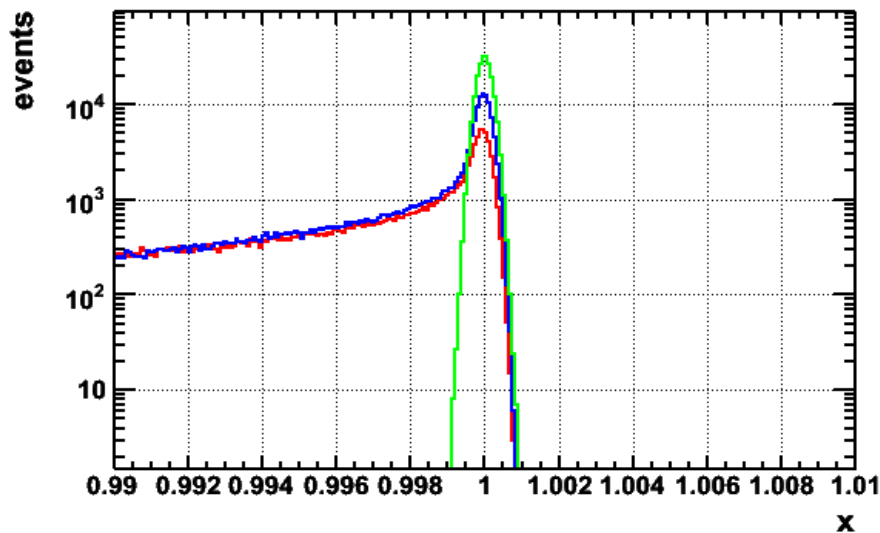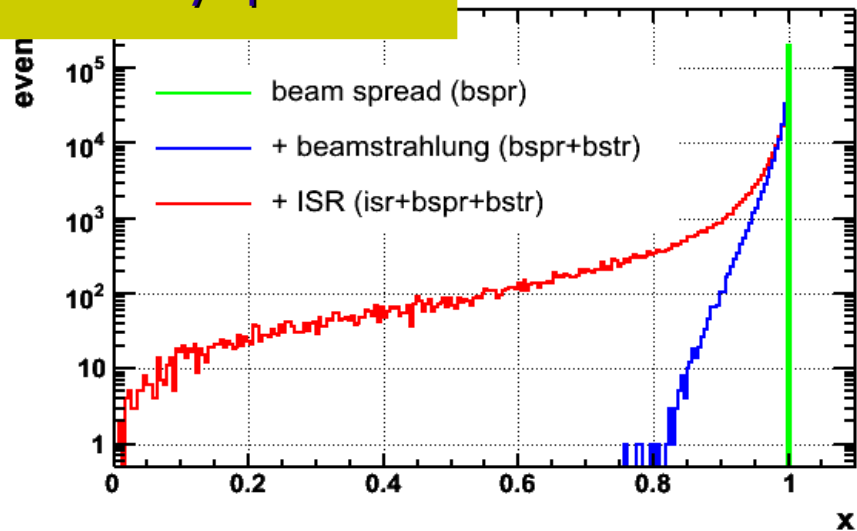# BPM Energy Spectrometry for ILC

Bino Maiheu
University College London
for LC-ABD WP 4.2
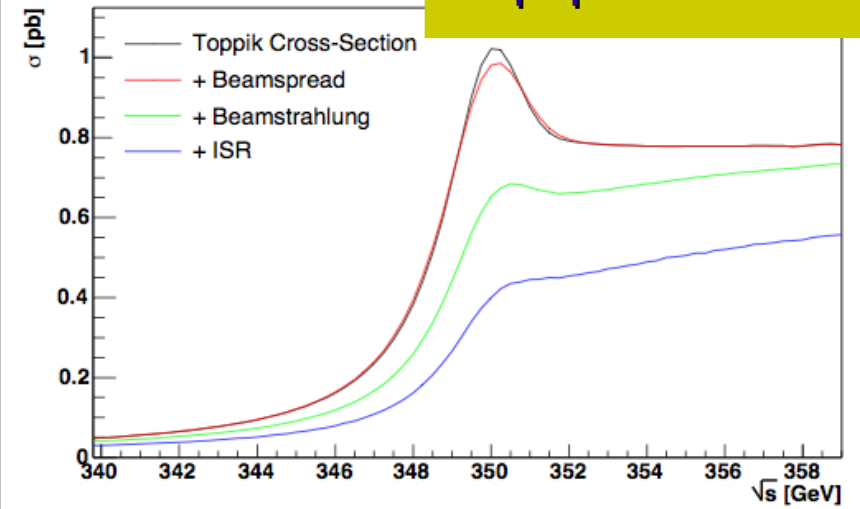
LC-ABD Meeting
IPPP Durham, 26 September 2006

Luminosity spectrum, physics case

Uncertainty on beam energy measurement contributes directly to the uncertainty on the ILC physics output...

Need for :
- energy measurement accuracy 10^{-4}
- stability and ease of operation
- minimal impact on physics data taking

BPM based beam energy measurement

WP 4.2 mission statement :
Study & design magnetic chicane for beam energy measurement using BPMs for a future linear collider

Royal Holloway University London: S. Boogert
Cambridge : M. Slater, M. Thomson and D. Ward
University College London: F. Gournaris, A. Lyapin, B. Maiheu, S. Malton, D. Miller and M. Wing

$\delta E/E \sim 10^{-4}$

$\eta \sim 5$ mm at center

At least $\delta x \sim 500$ nm needed
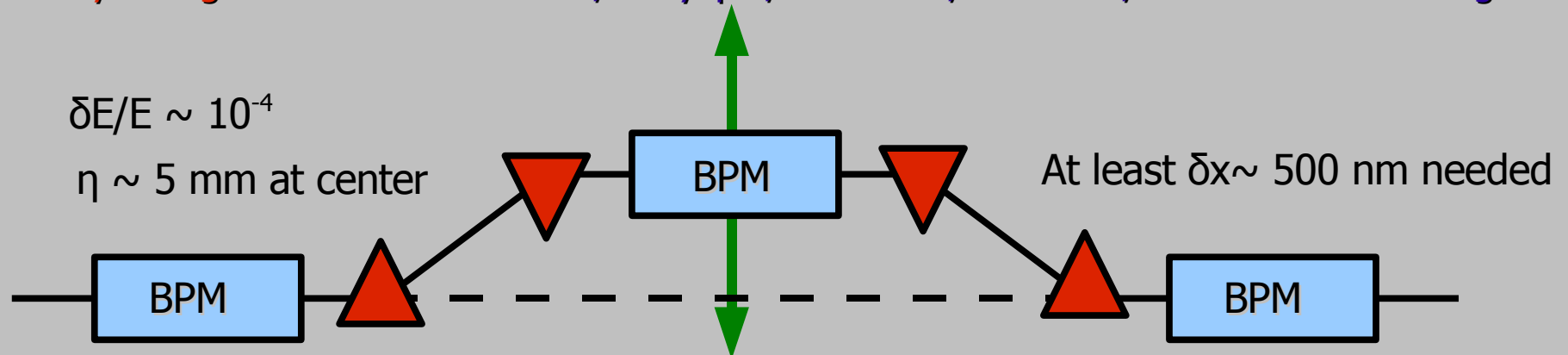
NanoBPM@ATF : test resolution, try different analysis methods, BPM stability tests, multi bunch operation, advanced electronics techniques, inclination of beam in BPMs.
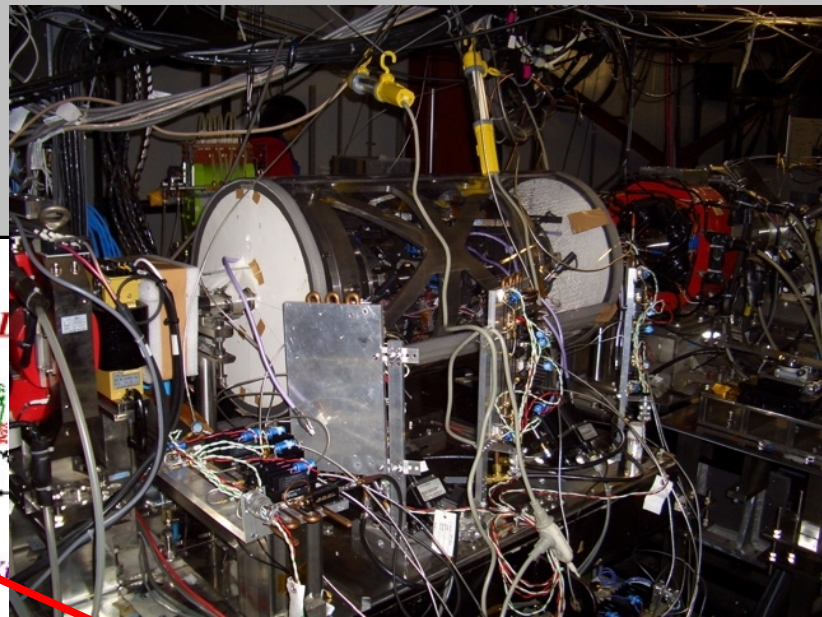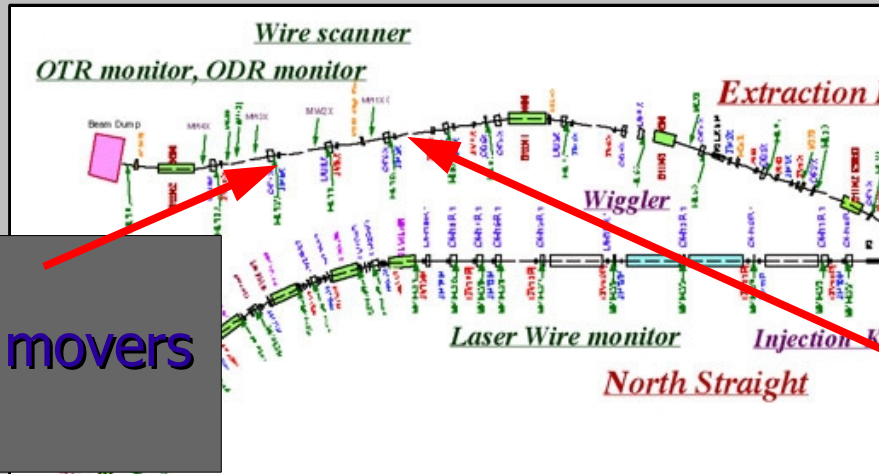
-> spectrometer aspects of BPMs can be tested

ESA@SLAC : test stability and operational issues with a full implementation of 4 magnet chicane and 3 BPM stations
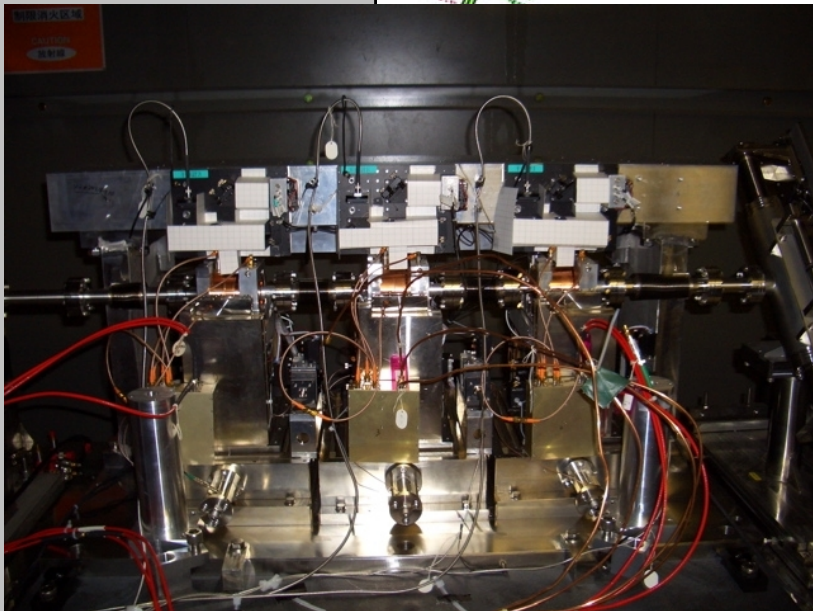
-> test of chicane prototype

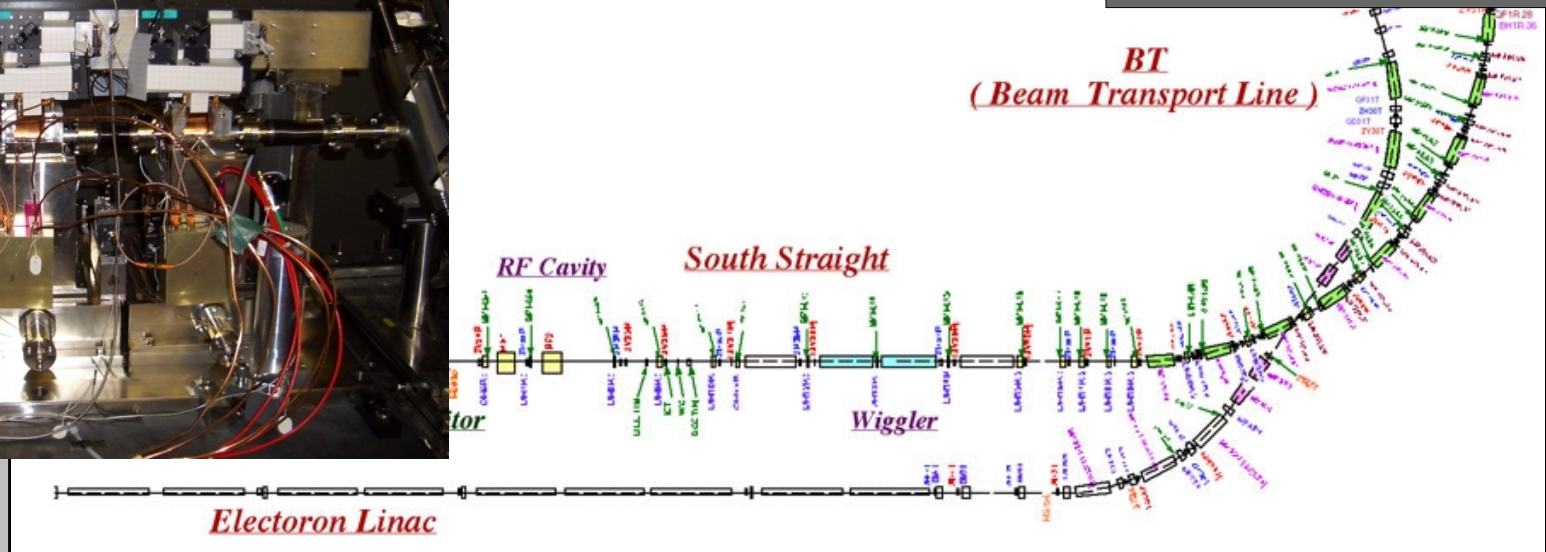# NanoBPM at ATF

Collaboration with LLNL, LBNL, SLAC and KEK

KEK BPMs on flexure piezo movers (x,y)

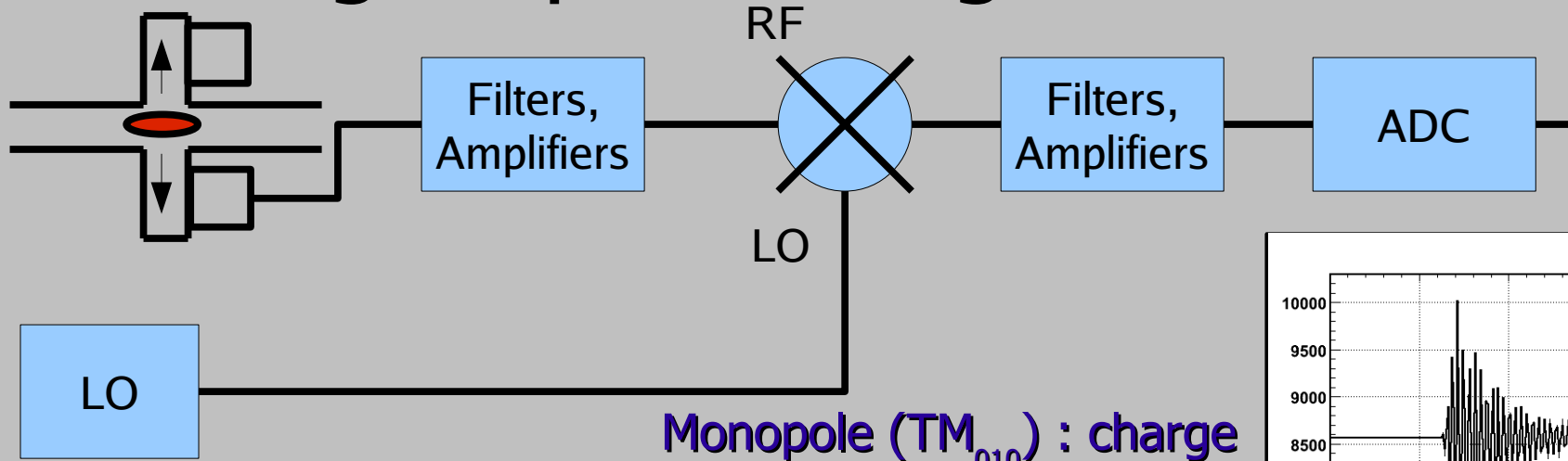BINP BPMs, each on hexapod (x,y,x',y') in SLAC/LLNL frame

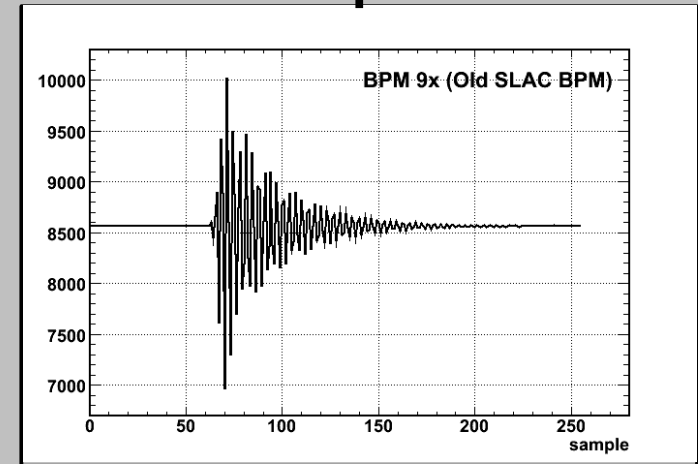# BPM signal processing in a nutshell

RF

Filters, Amplifiers

Filters, Amplifiers

ADC

LO

LO

Monopole (TM_{010}) : charge

Dipole (TM_{110}) : charge + offset + tilt
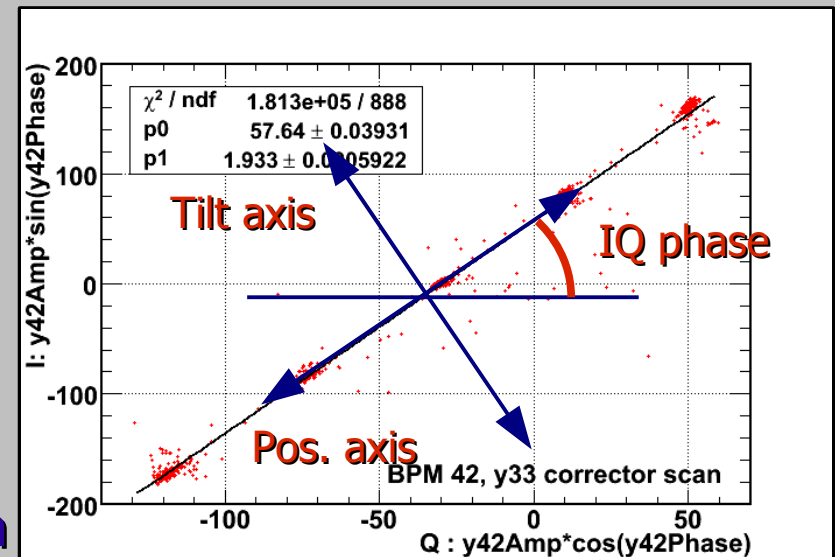

BPM 9x (Old SLAC BPM)

Determine Amplitude & Phase

- ➢ Fit waveform : $V = V_0 + A\, e^{-\Gamma(t-t0)} \sin[\omega(t-t_0) + \varphi]$
- ➢ Digital Down Conversion (DDC) :
  - ➢ Multiply waveform with $e^{i\omega t}$
  - ➢ Filter out 2ω component
 - ➢ Sample waveform at fixed t0Ref -> A, φ

Disentangle charge, offset and tilt :

Normalise signal to Ref (Q) Cavity

Tilt has $\pi/2$ phase difference to position

χ^2 / ndf	1.813e+05 / 888
p0	57.64 ± 0.03931
p1	1.933 ± 0.005922

Tilt axis

IQ phase

Pos. axis

BPM 42, y33 corrector scan

I: y42Amp*sin(y42Phase)

Q : y42Amp*cos(y42Phase)

ATF Results : resolution + systematics

- 2 stage down mixing, digitizer 14 bit
- Precise calibration using hexa-pod movers, cross calibration using corrector magnets
- Commissioned nanoGrid system (nm level XY encoder system) to monitor mechanical stability
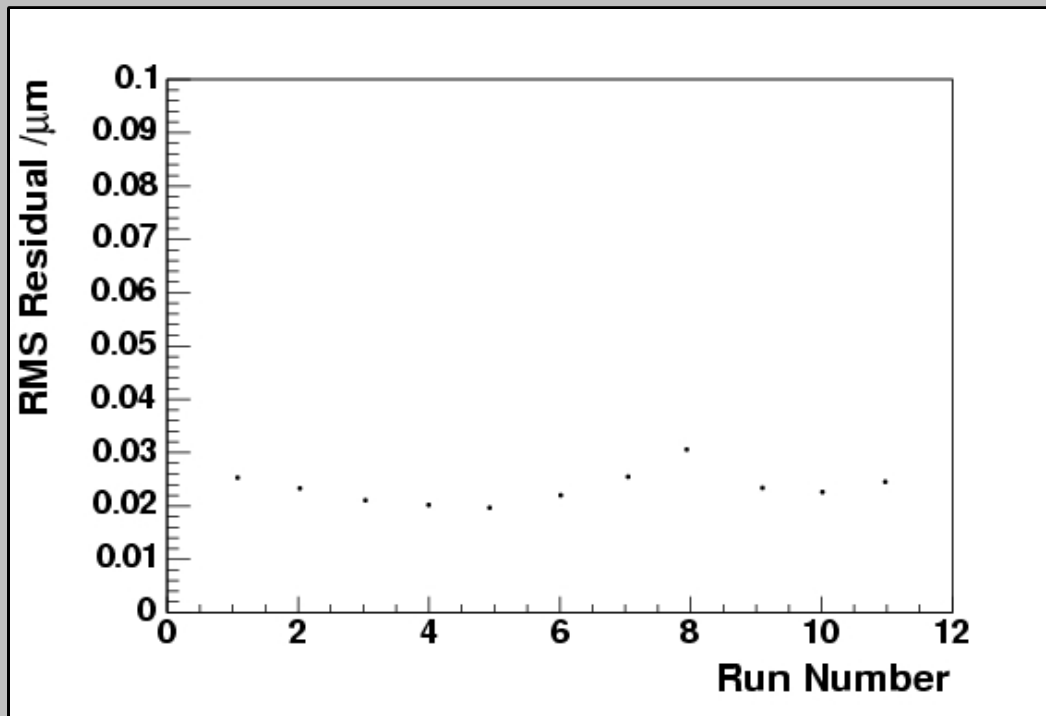
- Best resolution so far :
  - 16 nm
- Short and long-term :
  - drifts < 100 nm
- Clear systematic correlation seen Frequency & temperature :
$\Delta T \sim 0.25$ K -> $\Delta\omega \sim 65$kHz assuming typical offsets of beam 50 nm systematic scale change
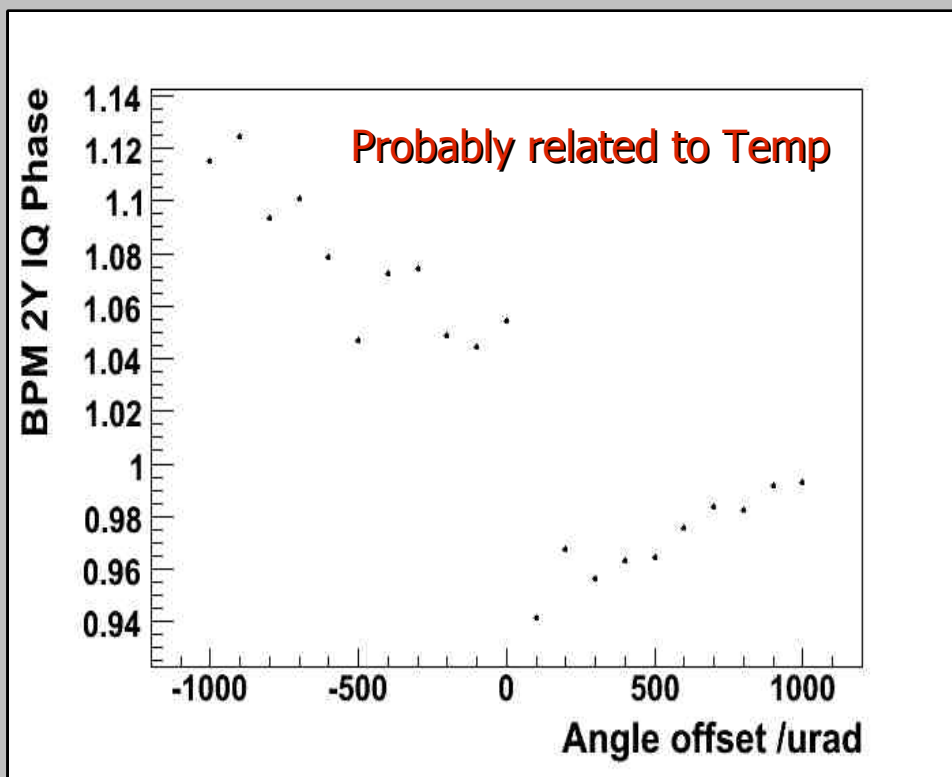
ATF Results : Beam inclination in BPM

Important for discussion 3 vs. 4 magnet chicane
data between -1000 and 1000 µrad
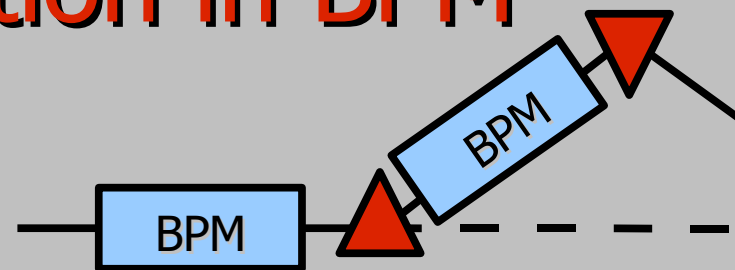
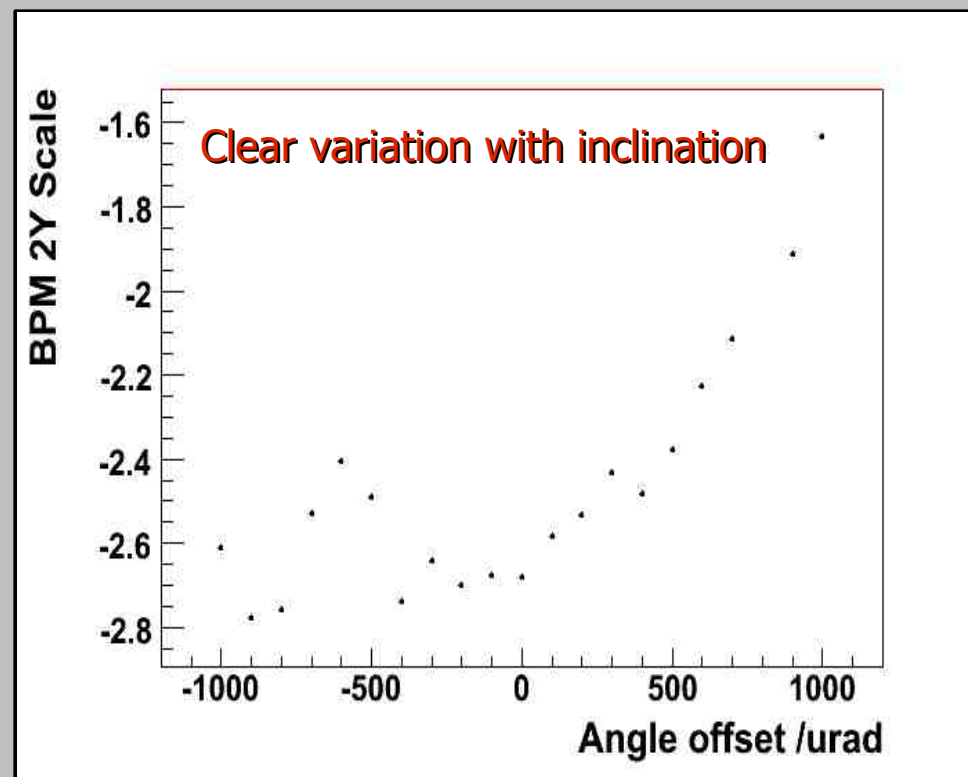No significant change in resolution, however :
clear change in calibration constants ! ————————➤ Further investigation !

IQ Phase

Position Scale

Probably related to Temp

Clear variation with inclination
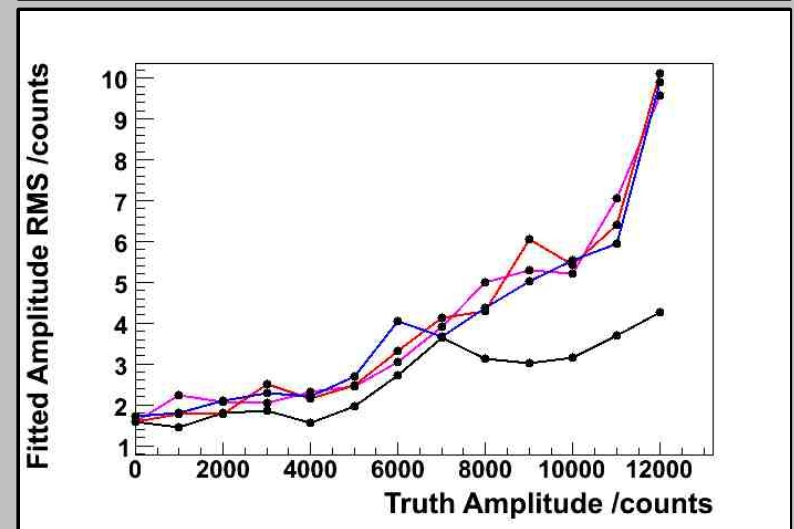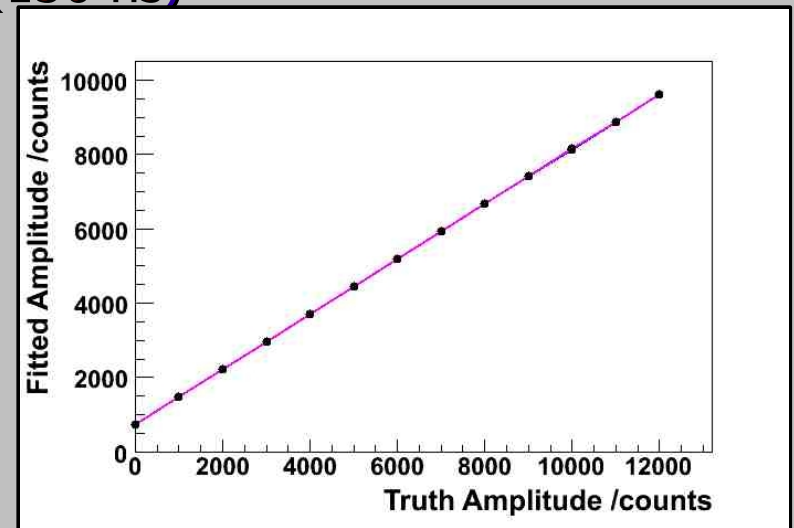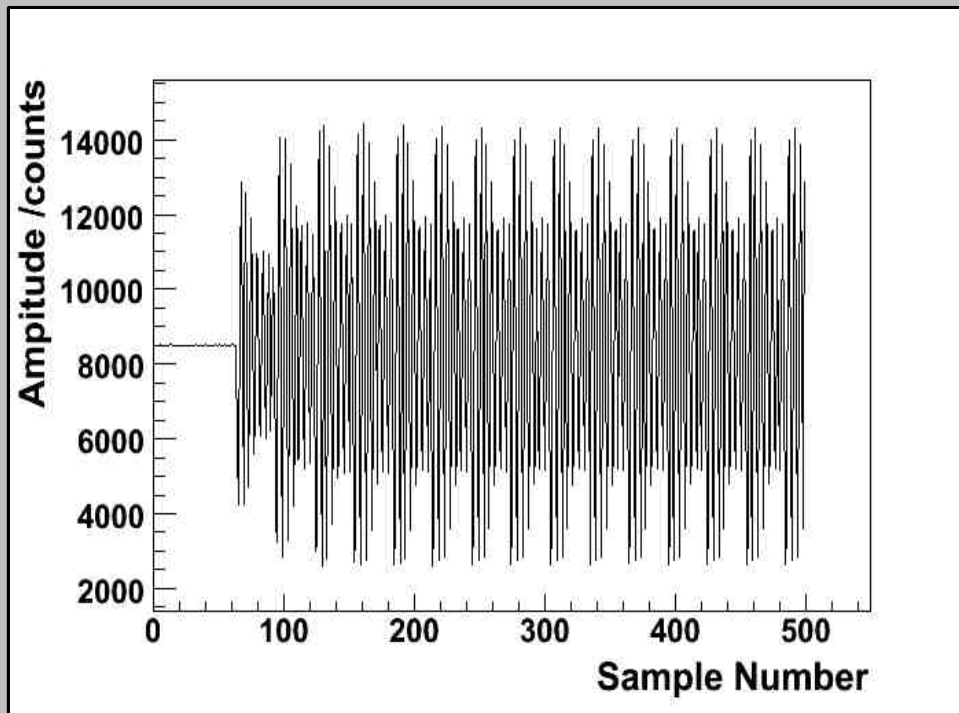
ATF Results : multibunch studies

Cavity BPMs must work with ILC bunch train...

➢ can we measure energy of individual bunches ?

ATF multi bunch data: bunch train of 3 bunches (150 ns)
proved difficult to steer down -> saturation...
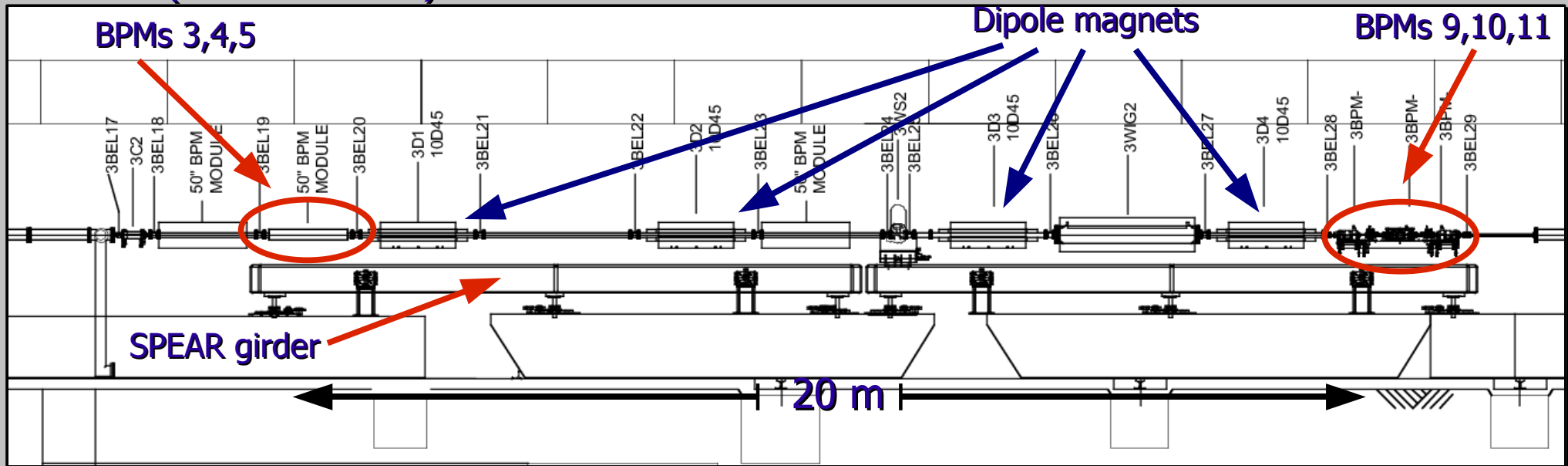
Simulation work bunch train:

➢ fitting algorithm seems to be performing well
➢ more study needed : phase advance, DDC ?

T474/T491 - ESA@SLAC

Collaboration with LBNL (Y. Kolomensky et al.), SLAC (M. Woods et al.) and Notre Dame (M. Hildreth et al.)

- January test run 2006 (4 days) : Commissioning of BPMs 31,32 and 1,2 upstream
- April run 2006 (2 weeks) :
  - Commissioning of new ILC prototype linac triplet (BPM 3,4,5), where BPM4 on x,y mover system
  - Commissioning of old SLAC BPMs (9,10,11)
  - Digitisation/signal processing optimization
- July run 2006 (2 weeks) :
  - Commissioning of Zygo interferometer system (BPMs 3,4,5) + energy BPM24 upstream
  - Further optimisation of hardware (down mixing)
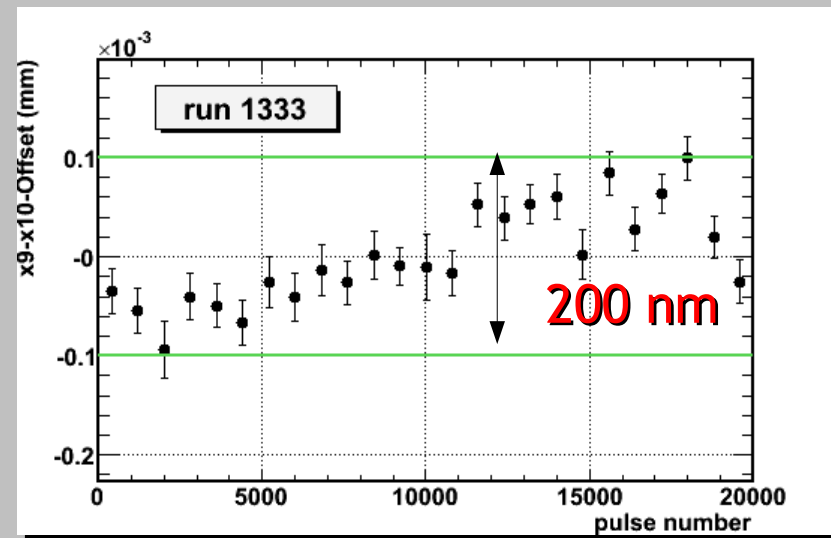 - Stability data taking with 10 BPMs, frequent calibrations
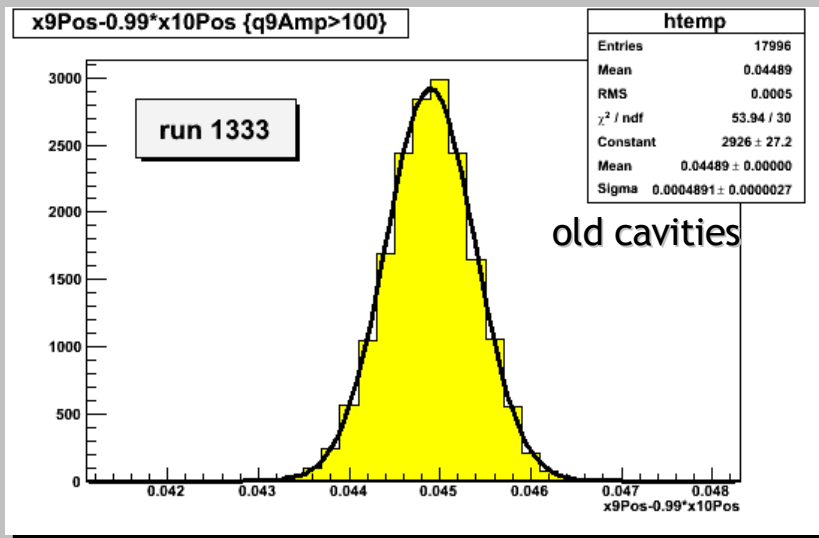
BPM systems used in ESA

- Rectangular cavities
  - x and y separated
- 2.856 GHz, high Q ~ 3000
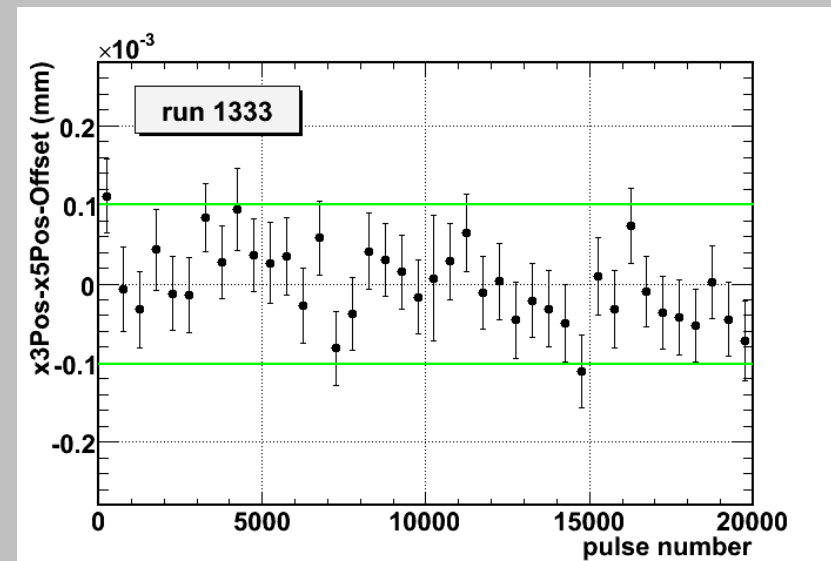- 20 mm aperture (0.8 ")
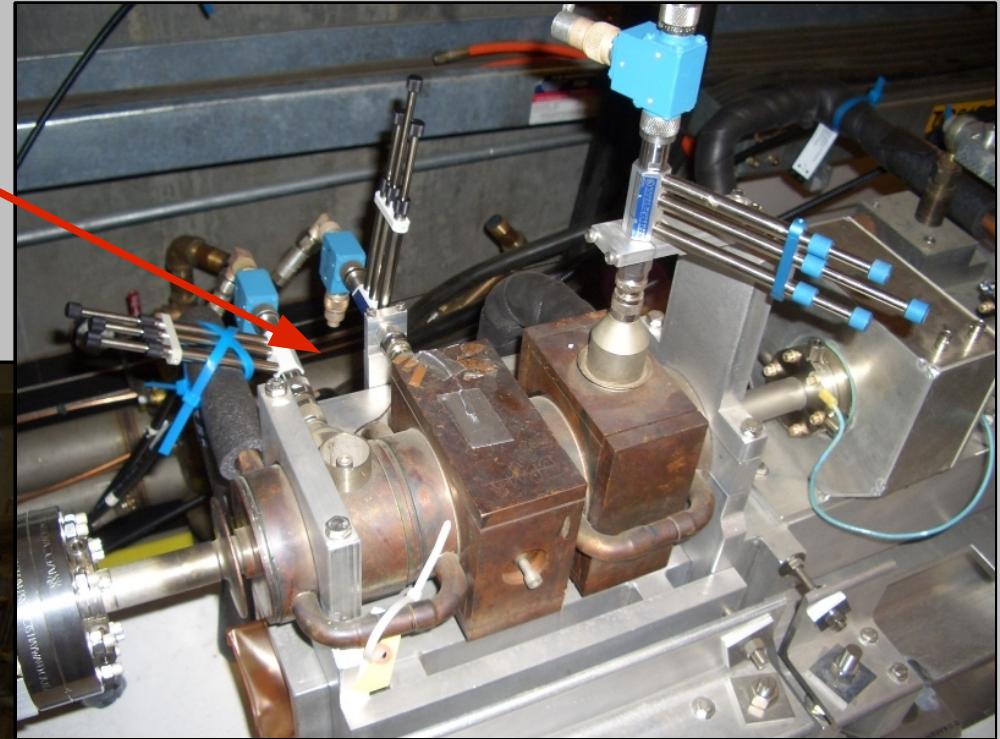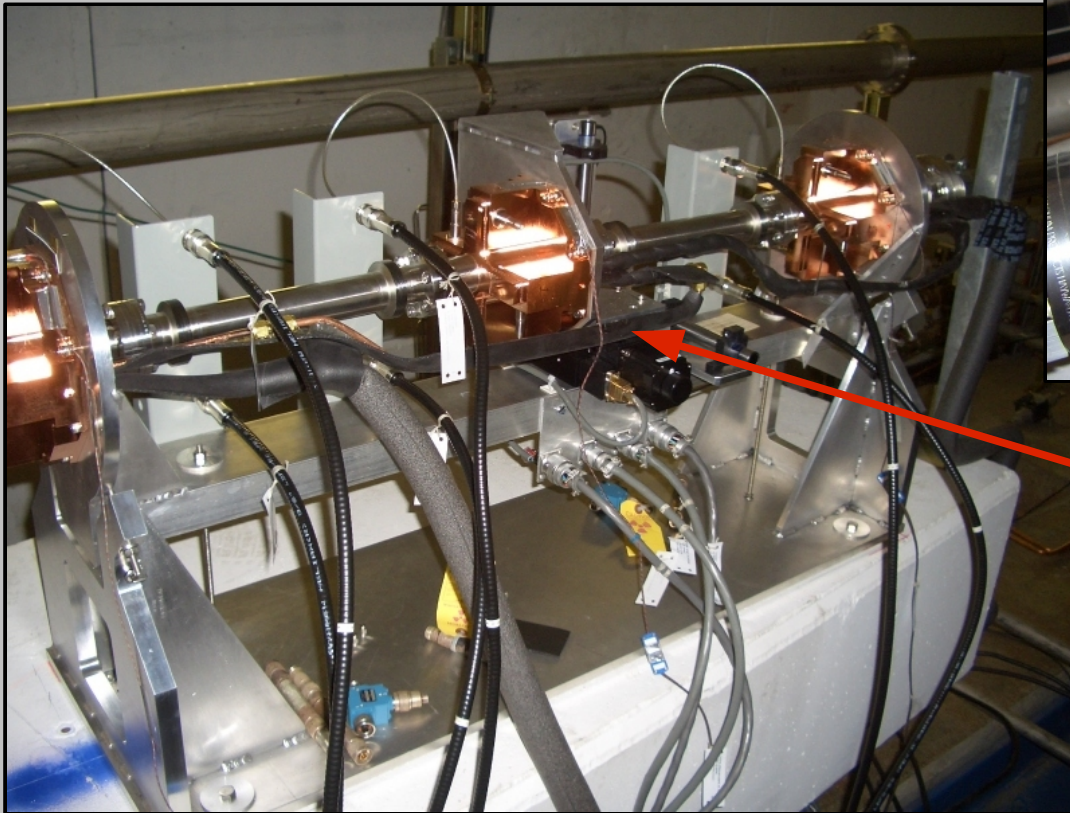
- C. Adolphsen, Z. Li
- ILC cold linac prototype cavities
- 36 mm aperture, 2.859 GHz
- low Q (~ 500)
- good monopole suppression

ESA Resolution & stability

Resolution : BPM 3-5: ~ 700 nm in x, BPM 9-11: ~350 nm in x

20k pulses ~ 30 min
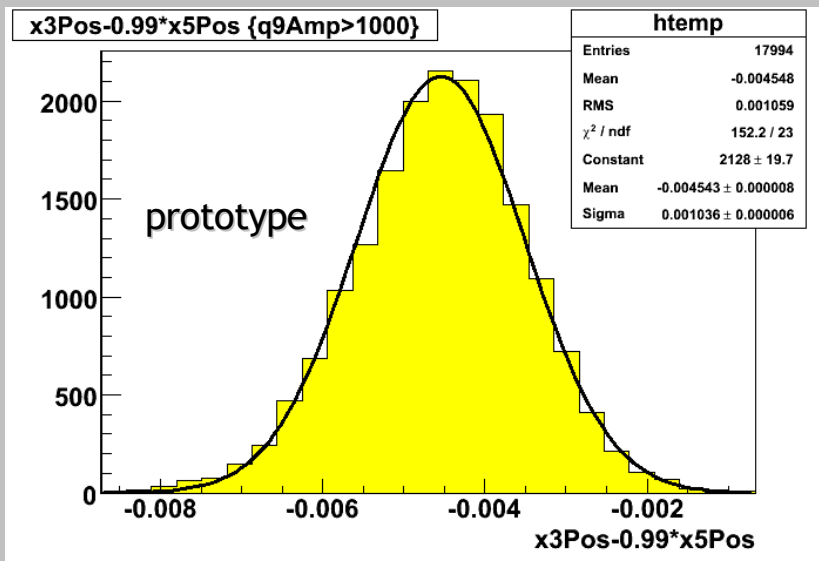
Automatic calibration

Important aspect of future spectrometer operation !

Corrector scans / setpoint calibration... lot of manual work needed

- Automatic setting of correctors with/without feedback
- Followed by mover scan on BPM4
- Set voltage level for each step in ADC
- Still need to implement automatic processing
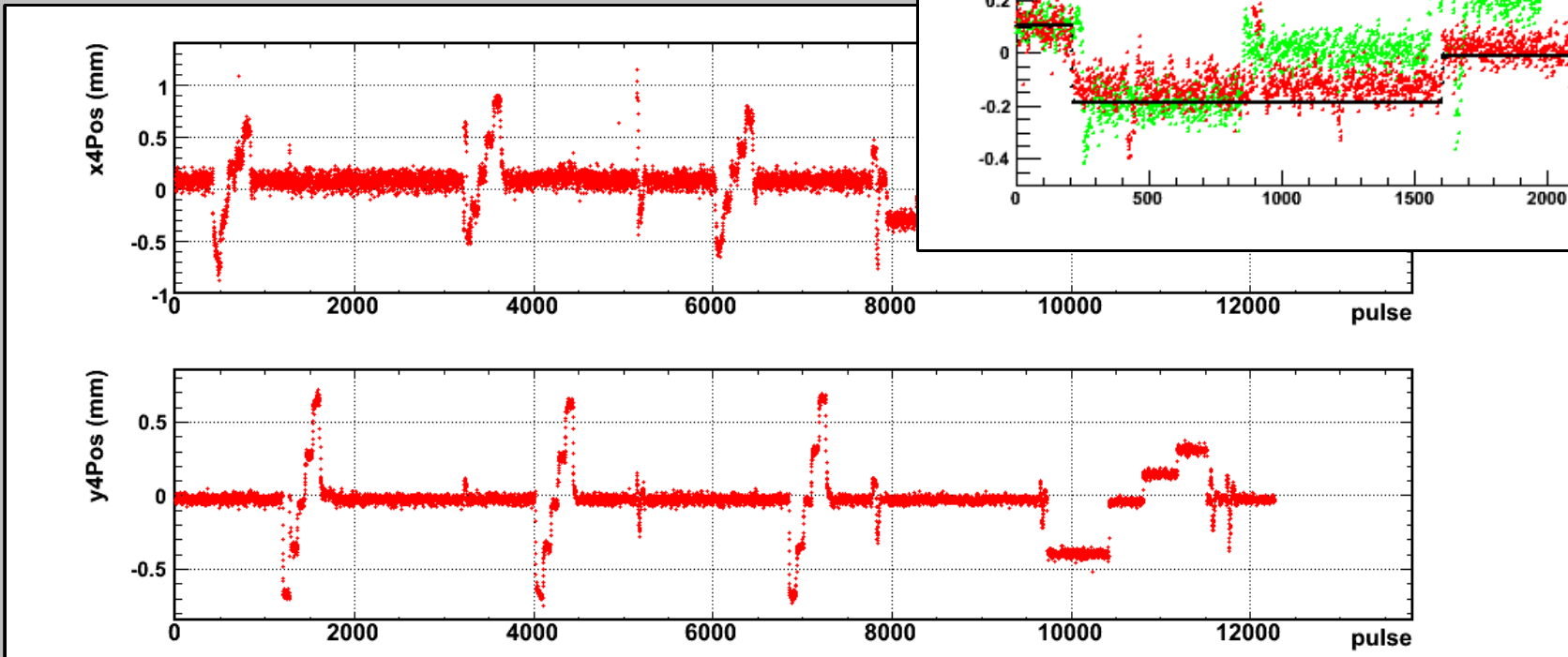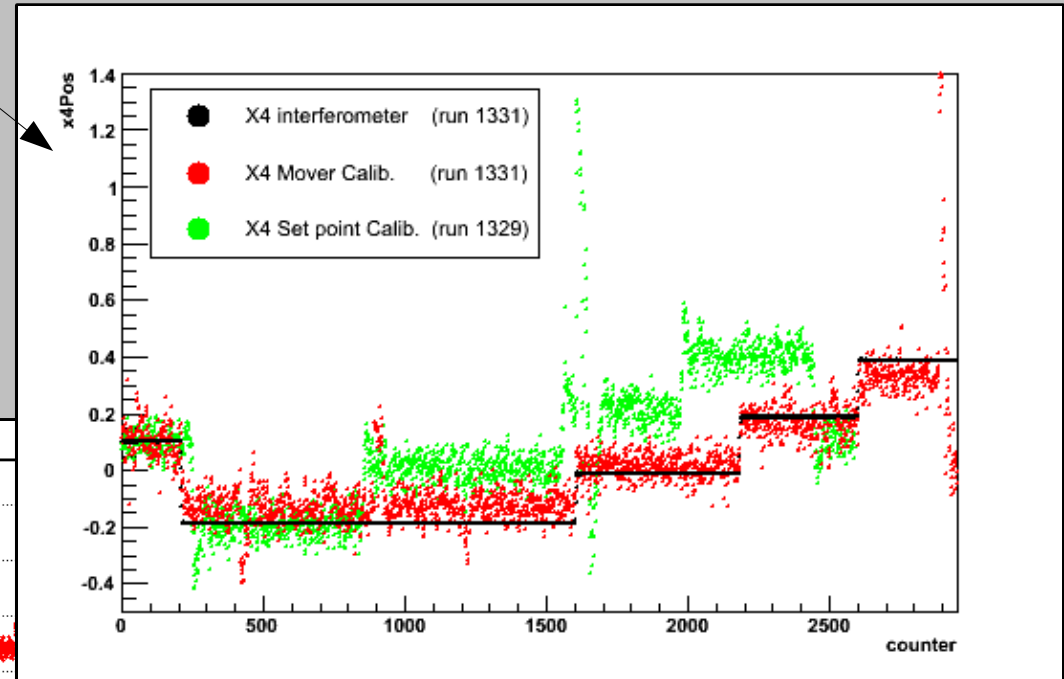
Spectrometer BPM prototype

Existing BPM designs not optimal for an energy spectrometer
- aperture (machine protection, resolution)
- resolution, stability
- monopole rejection (electric center stability)
- coupling -> decay time (multi bunch)

Designed new prototype (A. Lyapin)

- 30 mm aperture, 2.878 GHz, 1.3 MHz bandwidth
- theoretical resolution ~ 11.2 nm
- Al prototype by UCL workshop, Cu vacuum beam prototype by Mullard Space Science Lab (MSSL)

Al prototype
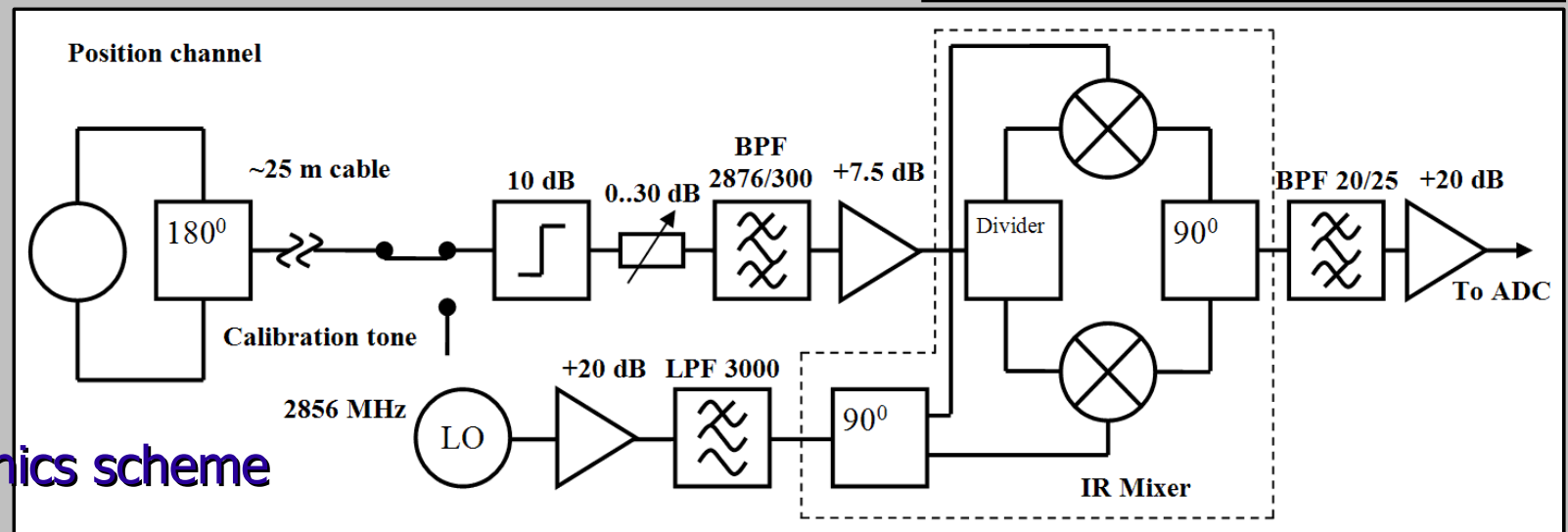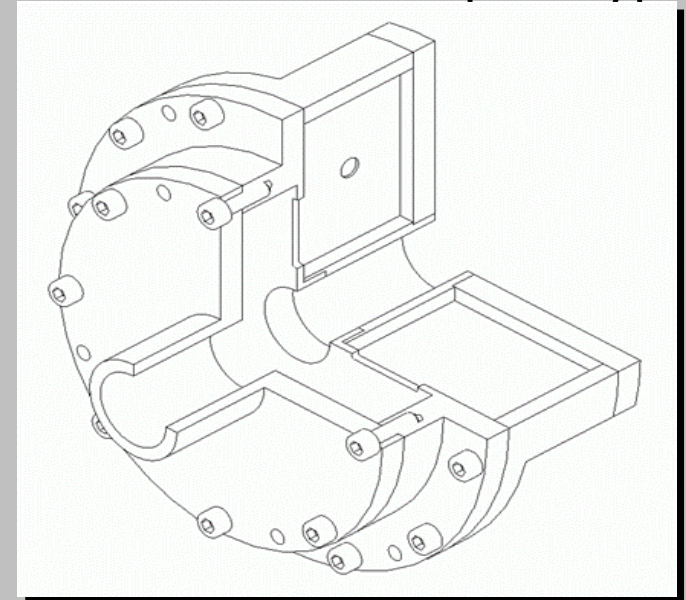
Proposed electronics scheme

Aluminium prototype for new BPM

Waveguide structure

Front face

Cavity (upside down)

Alex

Al prototype is done & ready for measurements at UCL & RHUL

Feed through

Fully assembled prototype

Chicane simulation

Currently most simulation work just generates "sampled waveforms"

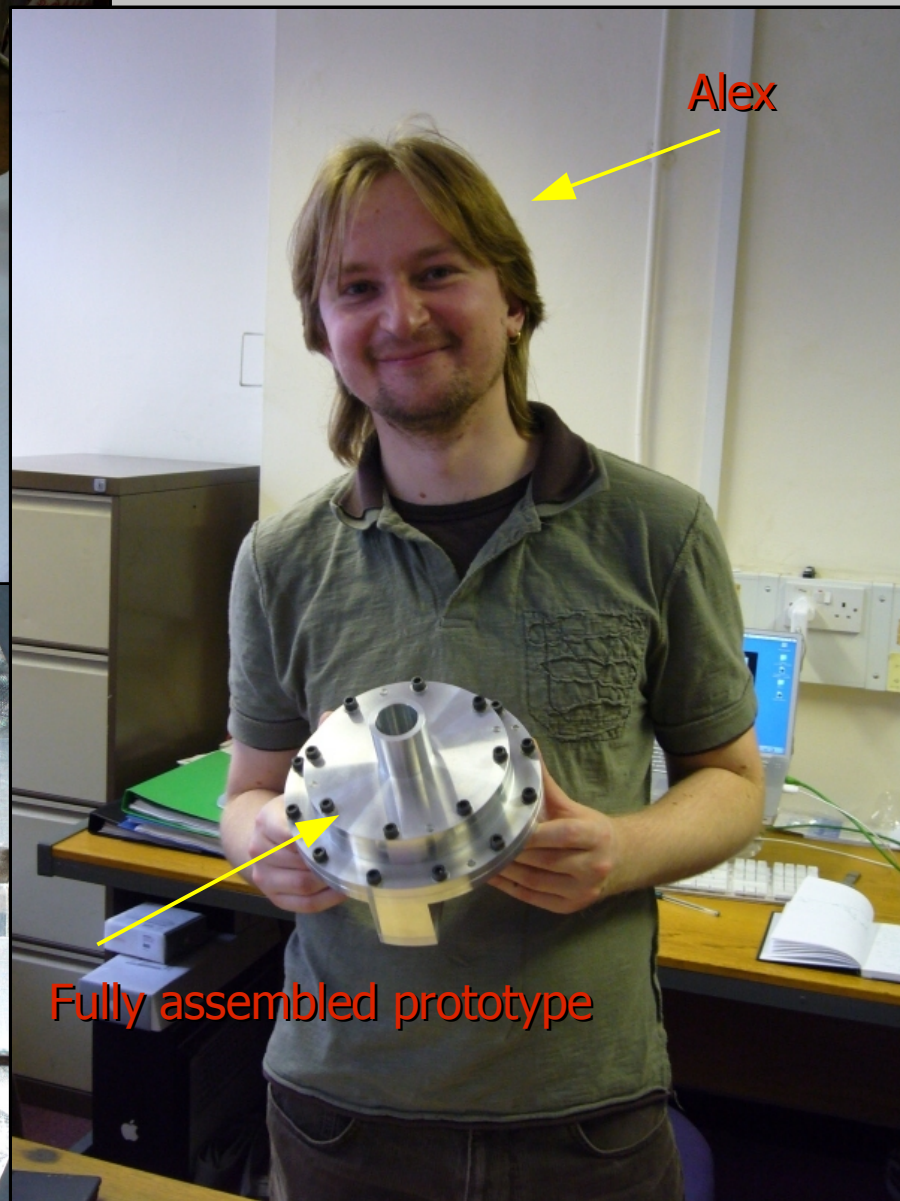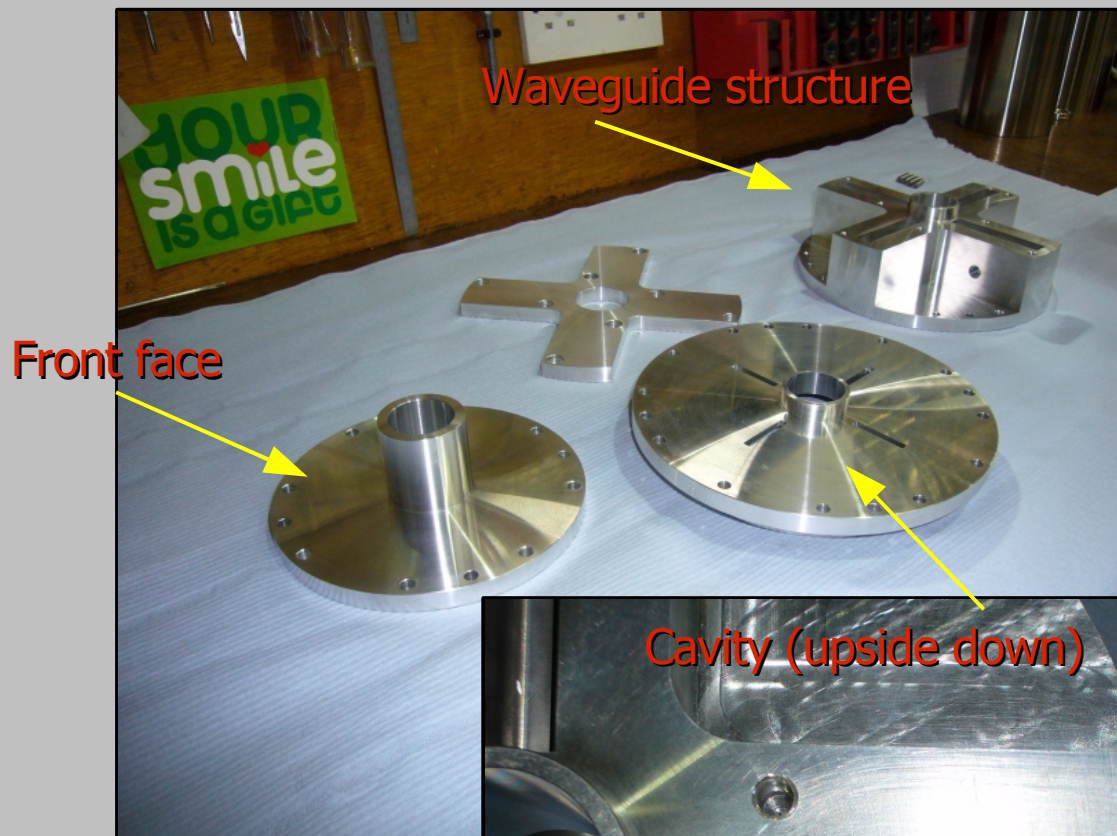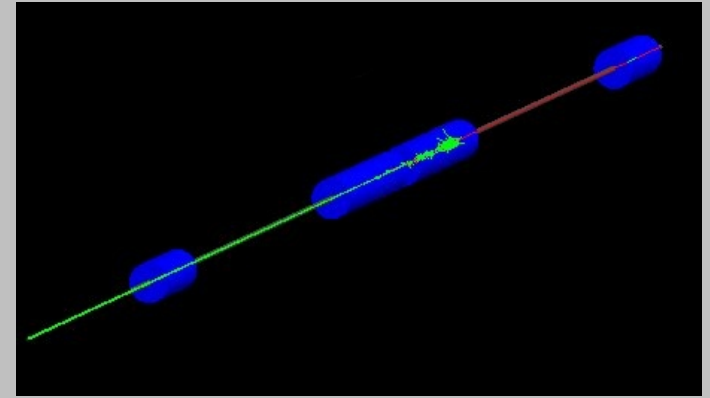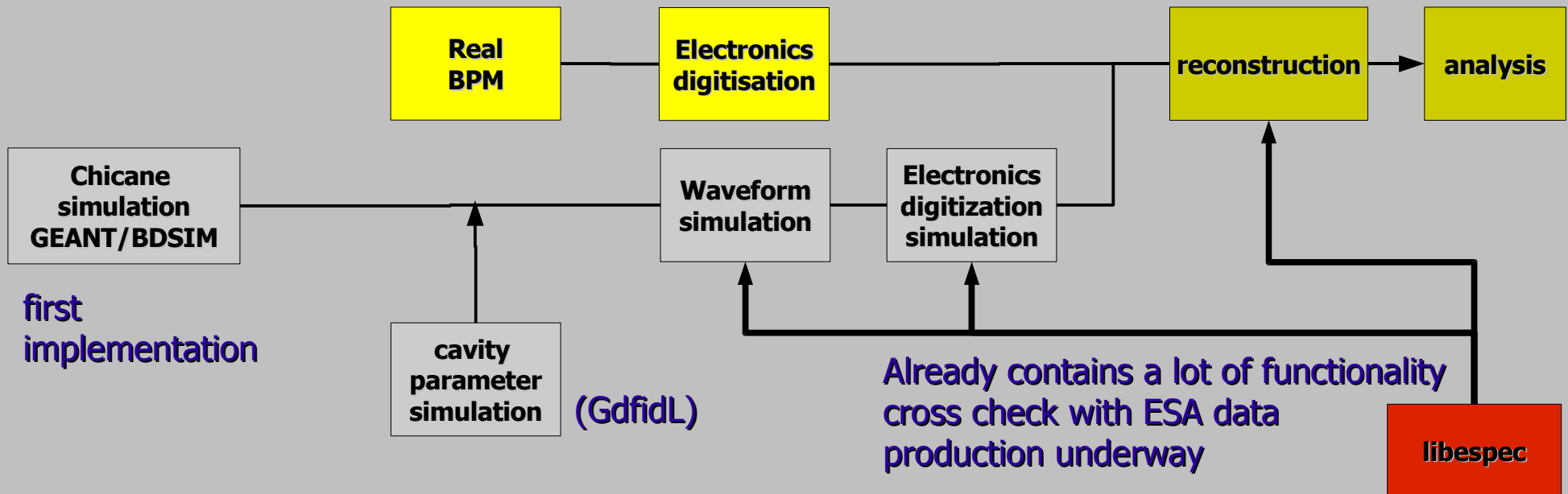Developing core library for full simulation :
- Uses physical units (easily portable between e.g. KEK & SLAC)
- Portability between platforms, e.g. import into LabVIEW
- Simulation of electronics : conversion loss, non linearity, digitization etc...
- Contains analysis routines as well -> simulation & real data analysis based upon idential set of routines

```
[Chicane
simulation
GEANT/BDSIM] ──────── [cavity
parameter
simulation] (GdfidL)

first
implementation

[Real
BPM] ──── [Electronics
digitisation] ──────── [reconstruction] ──> [analysis]

              [Waveform
              simulation] ──── [Electronics
                                digitization
                                simulation]

                                            [libespec]
```

Already contains a lot of functionality
cross check with ESA data
production underway

Future plans

Plans for ATF :
- long term stability studies
- multi bunch and additional tilt & spectrometer related tests
- use nanoGrid system to monitor mechanical stability of spaceframe
- new BPMs are planned to be installed to replace the KEK ones

Plans for ESA :
- Install 4 old refurbished magnets in beam line to form chicane (Jan. '07)
- Install & commission new spectrometer BPM prototype complete with temperature readout and x,y mover system
- Commission constant calibration tone system to monitor gain drifts in electronics
- Link BPM stations with interferometer system (M. Hildreth)

Plans for LC-ABD 2 :
- Develop BPM triplet to be deployed at mid-chicane location
- Long term tests of UK designed spectrometer specific BPMs