DESY Summer student program 2010

Analysis of the energy jitter in **FLASH**
(**F**ree electron **LAS**er in **H**amburg)

Mariana Khachatryan
University of Yerevan

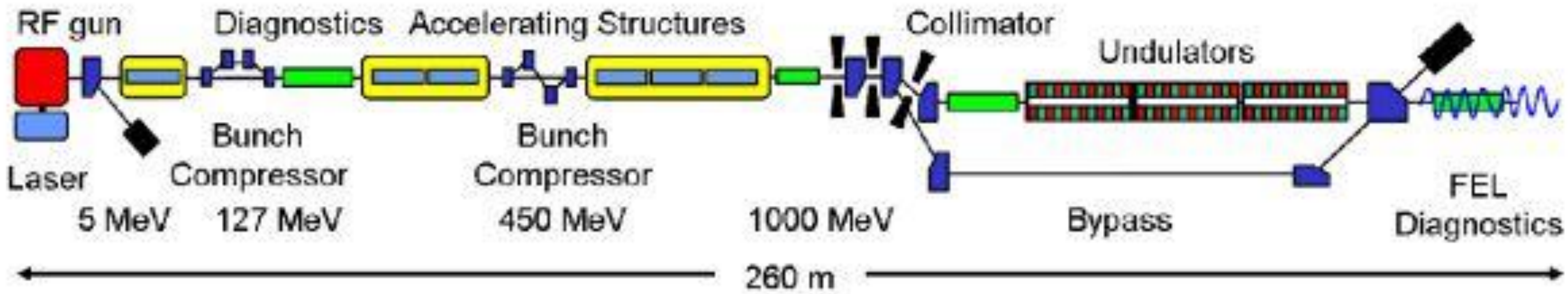
Nuria Fuster
University of Valencia

Contents.

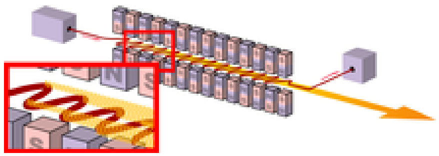
1.Introduction.

• FLASH is a VUV (vacuum ultra violet) Free Electron Laser (FEL) driven by a 1 GeV linear accelerator (linac) using superconducting technology.

• Schematic view of FLASH



- ❖ Photo injector
- ❖ Acceleration modules,RF cavities
- ❖ Optic components (quadrupoles, sextupoles)
- ❖ Bunch compressors
- ❖ Collimators
- ❖ Undulators



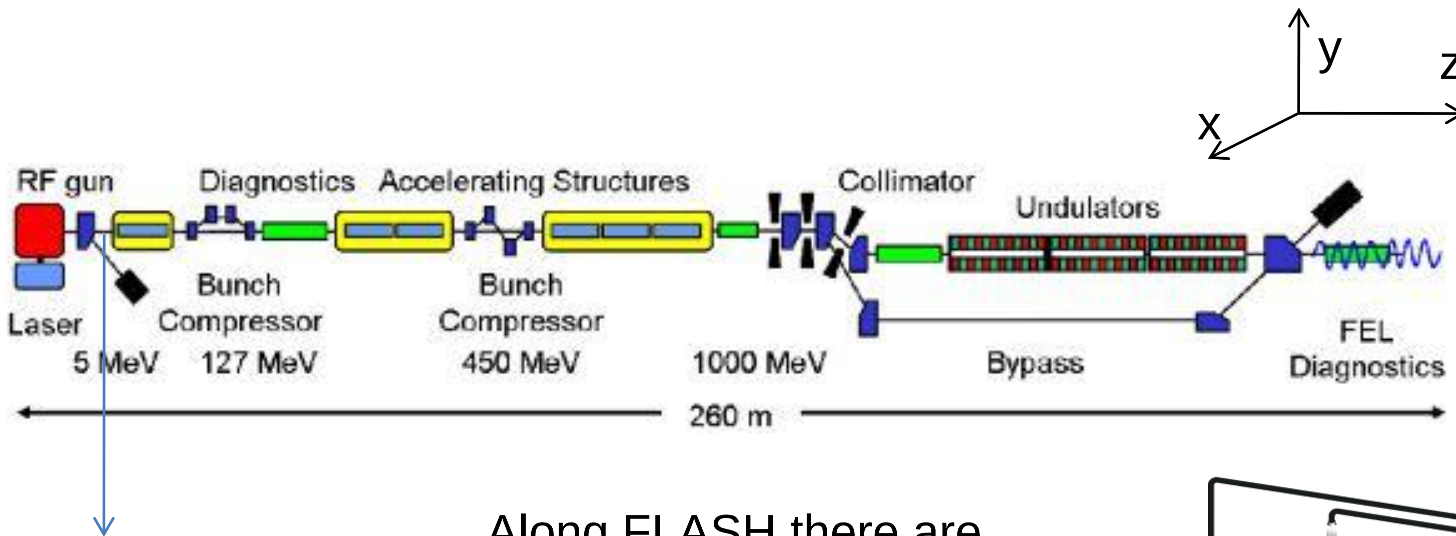
2.Motivation.

<u>FLASH goals:</u>

1. FLASH provide photon beams with high brilliance, it is a user facility for synchrotron researchers.
2. FLASH is a test accelerator for the XFEL (3 km) and ILC (30 km).
    - XFEL has been designed to get high brilliance at a small wavelength, the wavelength depends of the energy.
    - ILC is a linear collider and requires high luminosity (L is proportional to the number of bunches) for the collision experiments at high energy.

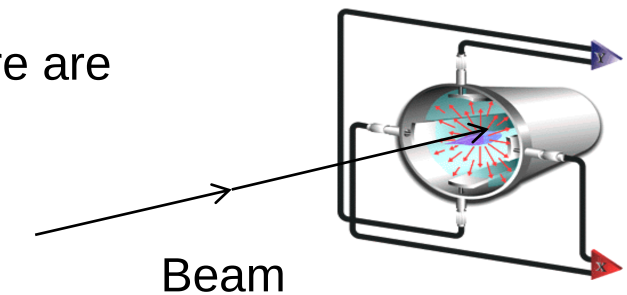
➡ Therefore it is important to produce and keep a beam with stable energy and position. Studies to get stable beams with long bunch trains are made at FLASH.

3.Setup.



Toroid: bunch charge measurement

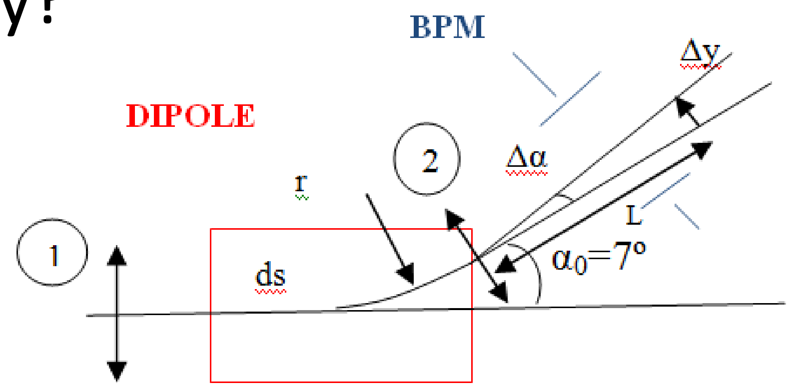
Along FLASH there are 24 BPMs to get position(x,y).



● All the data of the experiment is saved in DAQ (Data Acquisition System). The size of this experiments typically is about 15 Tbytes but in our study we use only a part.

2.Methodology.

How do we measure the energy?



1. Spectrometer principle:

- **<u>Components</u>:**

Dipole magnets : consists in a magnetic field perpendicular to the trajectory of the beam.

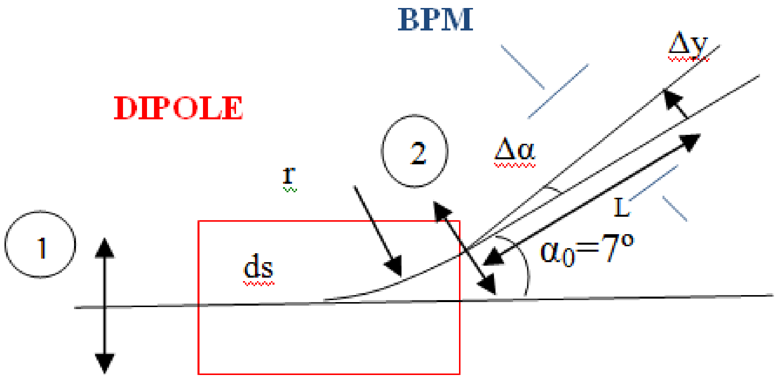
BPM : beam position monitor

- **<u>Physics</u>:** When a particle moves into a magnetic field the Lorentz force deflects the particle trajectory.

2.Methodology.

Applying the dynamic equation of uniform circular motion

$$\vec{F} = q(\vec{v} \times \vec{B}) \longrightarrow F = qvB = m\frac{v^2}{r} \rightarrow \frac{1}{r} = \frac{e}{p}B$$



After the dipole:

$$\alpha = \int \frac{ds}{r} = \frac{e}{p}\int B\, ds$$

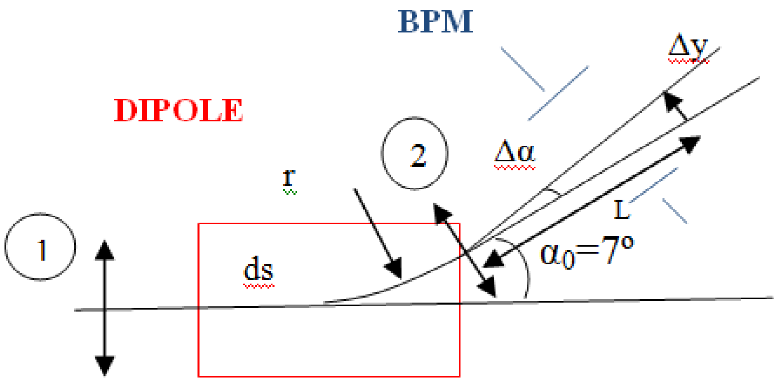
If we consider ultrarelativistic particles (E=pc)

$$E = \frac{e}{\alpha}\int B\, ds$$

2.Methodology.

- The angle is inversely proportional to the energy. $E = \frac{Constant}{\alpha}$

- The position in the y plane is proportional to the angle:



$$y = L * (\alpha - \alpha_0) \rightarrow dy = L * d\alpha$$

$$\alpha = \frac{C}{E} \rightarrow d\alpha = -\frac{C}{E^2} dE$$

$$dy = -\frac{C}{E} * L * \left(\frac{dE}{E}\right) = -\alpha * L * \left(\frac{dE}{E}\right)$$

$$\Delta y \propto \left(\frac{\Delta E}{E}\right)$$

- The variation measured by the BPM is proportional to the relative energy.

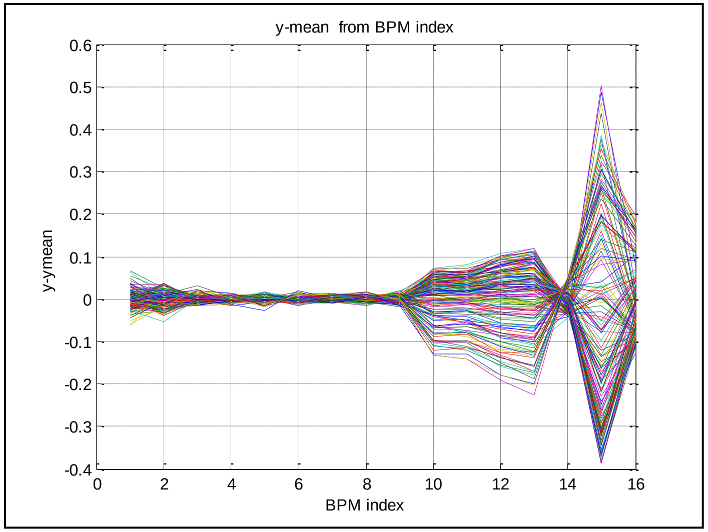
2.Methodology.

- Contributions to the energy measurement errors:

  - Noise of the BPMs

  - Systematic errors of the BPMs (wrong calibration, for example)

  - Trajectory inestabilities (before the dipole) because each bunch has a different initial position and angle.



Is there a method with which we can take away one of these errors?

3.SVD method.

- The second method to obtain the energy is using the Singular Value Decomposition Factorization (SVD).
- The mathematical meaning of SVD is that it decomposes the matrix M into three matrices like this:

M=U*S*V’

Where U and V matrices are orthonormal and the S is a diagonal matrix (the diagonal elements of which are called singular values).

- The physical meaning of SVD: shown with simulation in the following.

We apply SVD to the orbit matrix M(24,158), which is the relative beam position measurement .

$$M = \begin{pmatrix} y_{1,1} & \cdots\cdots & y_{1,158} \\ \vdots & & \\ y_{24,1} & & \end{pmatrix} \Rightarrow U*S*V'$$

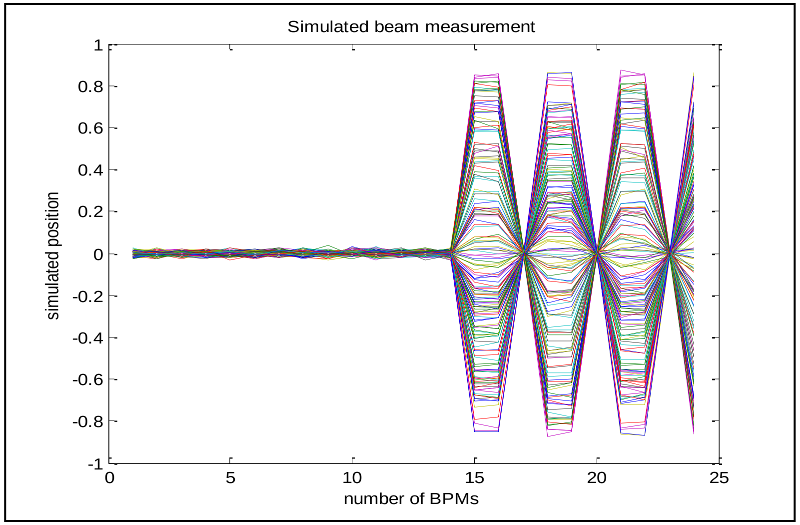
3.SVD method.

- We made simulated BPM noise which is a matrix M^{noise} with a size (24*158) with Gaussian random numbers with a σ =0.01mm .

$$M^{sim} = M^{E} + M^{noise}$$

M^{E} Is a matrix of simulated trajectory for energies $\frac{\Delta E_j}{E}$ between [-1,1] in units of 10^{-3} .

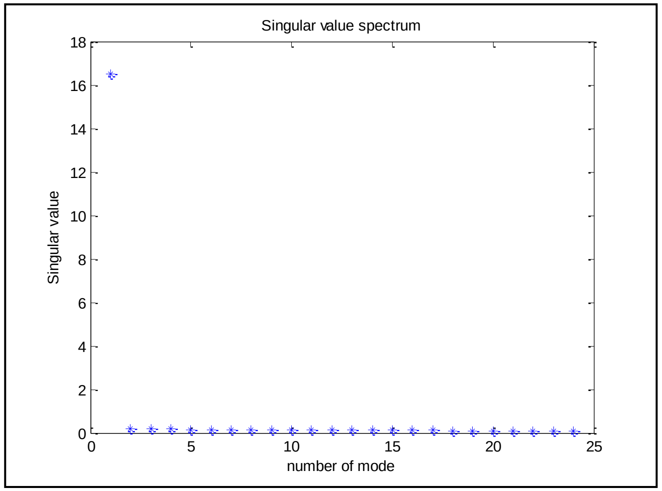
- On the figure below you can see the plot of the matrix M^{sim} .



Simulated beam measurement

3.SVD method.

- Results of SVD applied to M^{sim}.
- The S matrix (diagonal)



The first value corresponds to the simulated trajectories for random energies.

Now we want to calculate energy extracted from SVD. The row of U corresponding to the singular value S_{11} is U_{i1} and corresponding colum of V is V_{j1} .

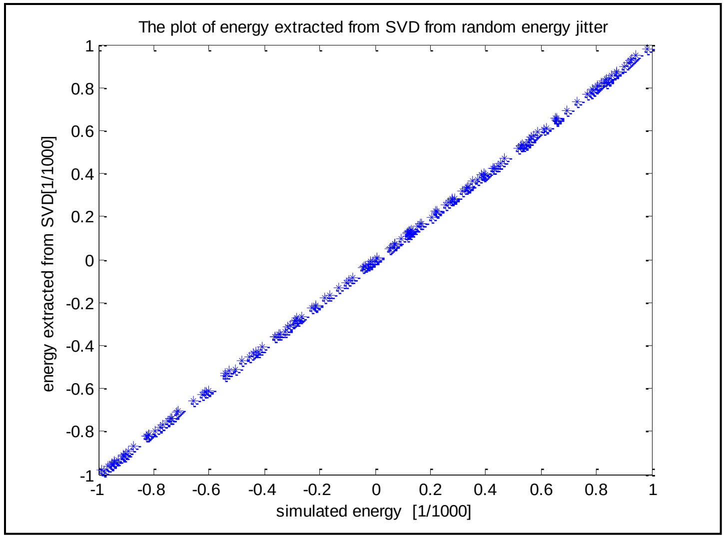
First we calculate y position from the BPM6PYP (this is the 15th BPM, which is used in experiment data from FLASH):

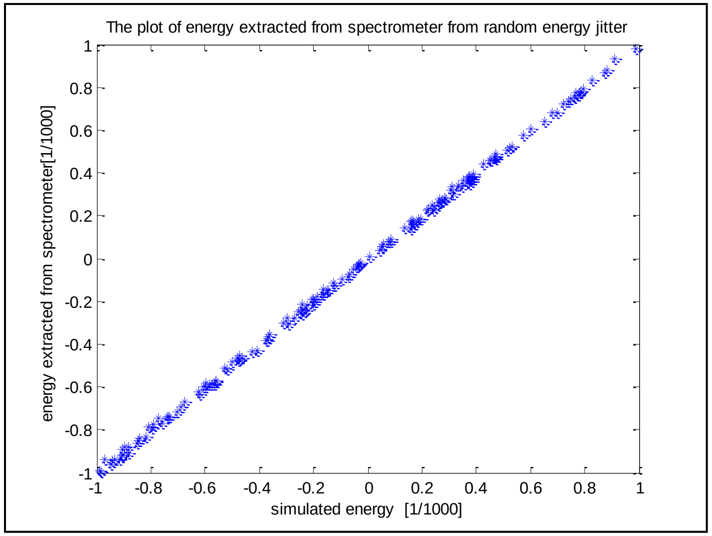
$$y_{15,j} = U_{15,1} \times S_{1,1} \times V_{j,1}$$

Then with this we extract the relative energy from SVD $\frac{\Delta E^{SVD}}{E}_j$.

3.SVD method.

- Below we can see the plot of energy extracted from SVD from the simulated energy.

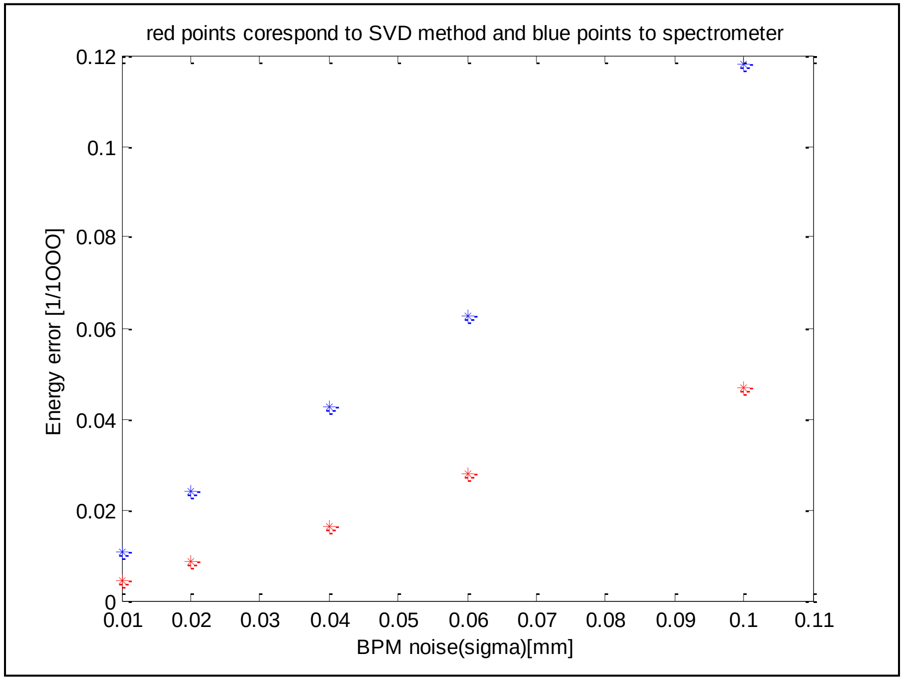




- The standard deviation of the difference of this two energies gives us the error of simulated energy measurement from SVD method. For the chosen sigma it is equal 0.004 [10^{-3}].
- We calculate the energy from spectrometer from the position data in matrix M^{sim}
- The standard deviation of this energy minus the simulated energy gives us the error of simulated energy measurement from spectrometer method. For the chosen sigma it is equal 0.0123[10^{-3}] .
- As we can see the error E^{SVD} is smaller than the error of E^{Spect}

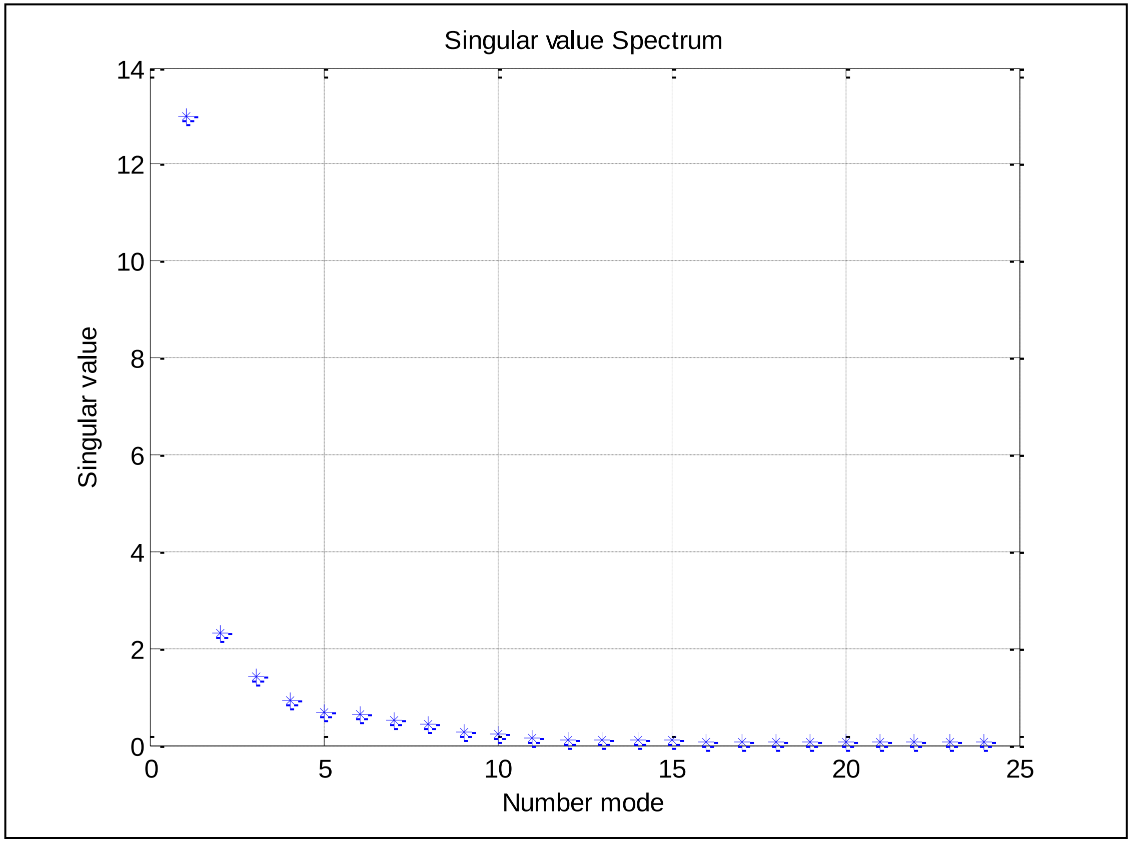
3.SVD method.

- Finally we made the plot of this two errors for different BPM noise (σ) (see in the figure below).



3. Experimental Results.

- We apply the SVD descomposition to the experimental data and we extract the energy corresponding to the stronger motion mode.



3. Experimental Results.

What we learn from this analisis are:

● The results of E^{SVD} are more precise than the E^{Spect} method because:

● We get the energy from the data of all BPMs (downstream the dipole) , so we have more measurements therefore less error of measurement.

● We separate the trajectory changes due to energy instability (present only downstream the dipole) from trajectory instabilities (present upstream and downstream the dipole).

Conclusions

- We have compared two methods to obtain the energy of electron beam :
  - Using simulated data
  - Using experimental data
- We get more precise E measurements for SVD method.
- With the SVD we separate different type of beam instabilities (energy, trajectory…).
- A more precise knowledge of energy ,energy jitter and other trajectory instabilities can help to improve the accelerator performance.
- More studies will follow.

Aknowledgements

We would like to thank Professor Joaching Meyer and all the people who make possible the DESY Summer Student program to give us the opportunity to come here and get such great experience. And we also would like to thank our supervisors P. Castro, N. Walker and J. Carwardine for their support in all questions that we had, for many hours of patient explanations, corrections, as well as for guidance throughout the whole summer student program.