β^* in the Tevatron + α

Budker Seminar
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   2. From Now
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I. AC Dipole

I. AC Dipole – 1. Introduction

- AC Dipole Is…
  - An oscillating dipole with controlled f and B_{max}

  → Used in AGS & RHIC @ BNL to avoid spin resonance.
  - Remember forced harmonic oscillators and resonance.
  - The phase space position can be "controlled".

  → "Nondestructive Controllable Kicker".
- Here, Now @ FNAL…
  - To study linear and nonlinear dynamics of Tevatron with Better BPM's and IPM.
- In Future…
  - One for LHC??

I. AC Dipole - 2. From Now

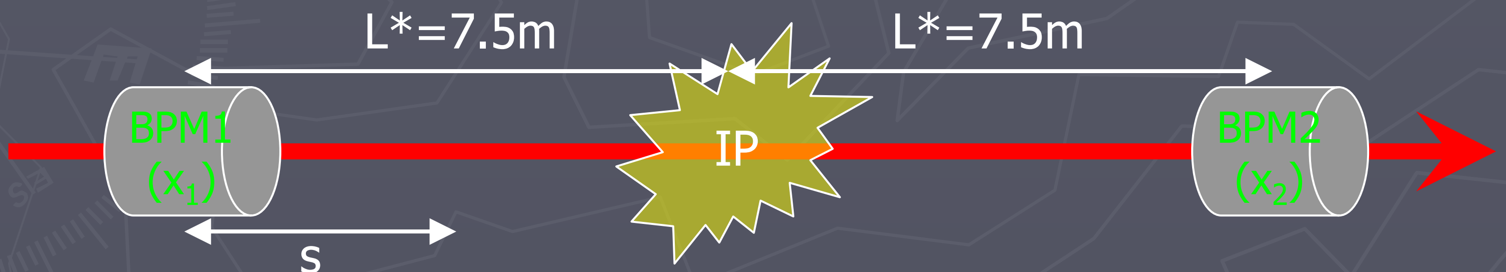
- It's just started!
  - From now, study, simulation, design, construction, measurements, analysis and write up…
- Accelerator Physics and Technology Seminar
  - 11/17/2005 "TBA (About AC Dipole)" by Mei Bai (BNL)

II. β* Measurements in the Tevatron

II. β* Measurements in Tevatron - 1. Theory

- Motivation:
  - It is not easy to directly measure beta functions.
  - With resolutions of new BPM system in Tevatron, beta around IP can be measured in the following way:
- Two BPM's at IP w/ no magnetic fields in-between.

→ Particles drift. → (x_1, x'_1) can be measured TBT.



II. β* Measurements in Tevatron - 1. Theory

- If we know (x,x')… [Based on Syphers' BeamDocs]
  - Betatron Oscillation:

$$x(n) = A\sqrt{\beta}\cos(2\pi\nu n + \delta)$$

  - TBT Average:

$$\langle x^2\rangle = A^2\beta\langle\cos^2(2\pi\nu n + \delta)\rangle = \frac{1}{2}A^2\beta$$

  - Similarly:

$$\langle xx'\rangle = -\frac{1}{2}A^2\alpha \qquad \langle x'^2\rangle = \frac{1}{2}A^2\gamma$$

$$\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2} = \frac{1}{2}A^2$$

II. β* Measurements in Tevatron - 1. Theory

- CS Parameters:

$$\beta_1 = \frac{\langle x_1^2 \rangle}{\sqrt{\langle x_1^{\ 2} \rangle \langle x_1'^2 \rangle - \langle x_1 x_1' \rangle^2}}$$

$$\alpha_1 = \frac{-\langle x_1 x_1' \rangle}{\sqrt{\langle x_1^{\ 2} \rangle \langle x_1'^2 \rangle - \langle x_1 x_1' \rangle^2}}$$

$$\gamma = \frac{\langle x_1'^2 \rangle}{\sqrt{\langle x_1^{\ 2} \rangle \langle x_1'^2 \rangle - \langle x_1 x_1' \rangle^2}}$$

- β around IP and etc:

$$\beta(s) = \beta_1 - 2\alpha_1 s + \gamma s^2$$

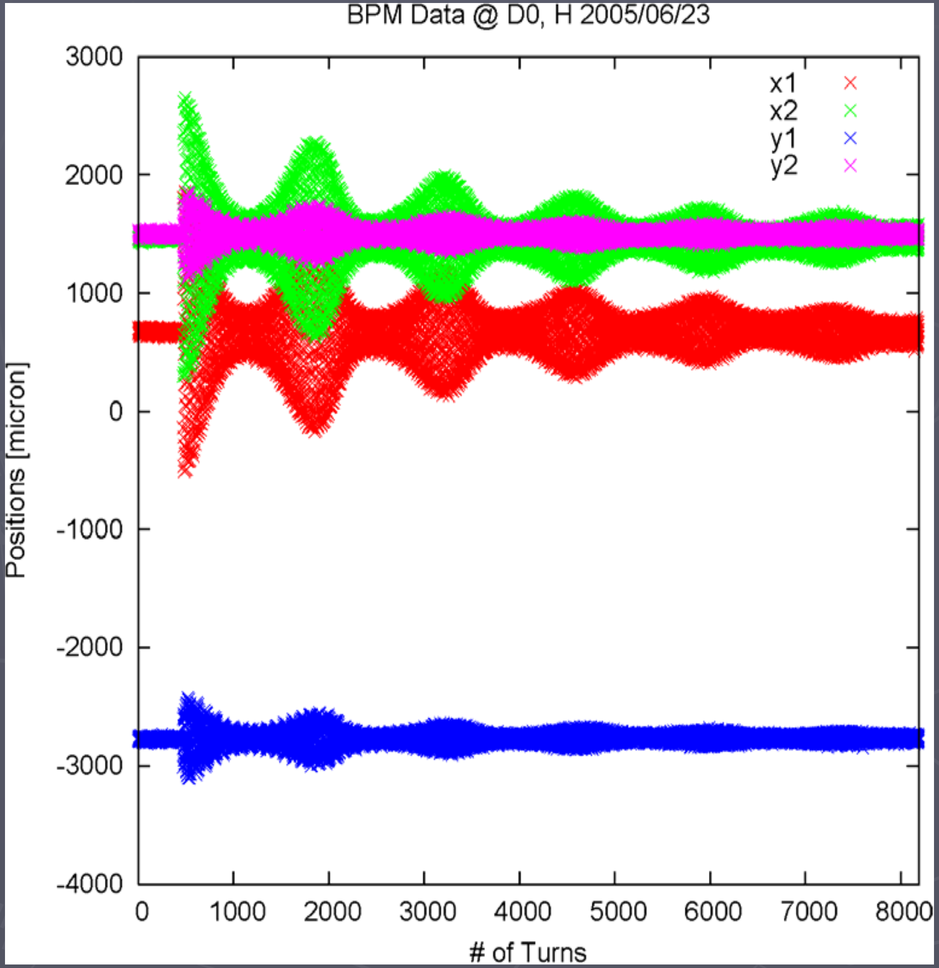
$$\beta^* = \beta(L^*)$$

$$\beta_{\min} = \frac{1}{\gamma}$$

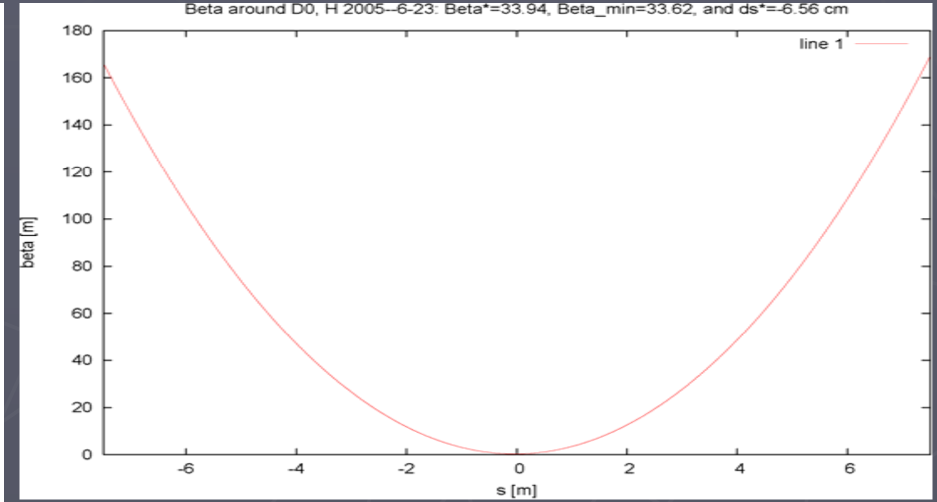
$$\Delta s^* = \frac{1}{2}\frac{\alpha_1 + \alpha_2}{\alpha_1 - \alpha_2} L^*$$

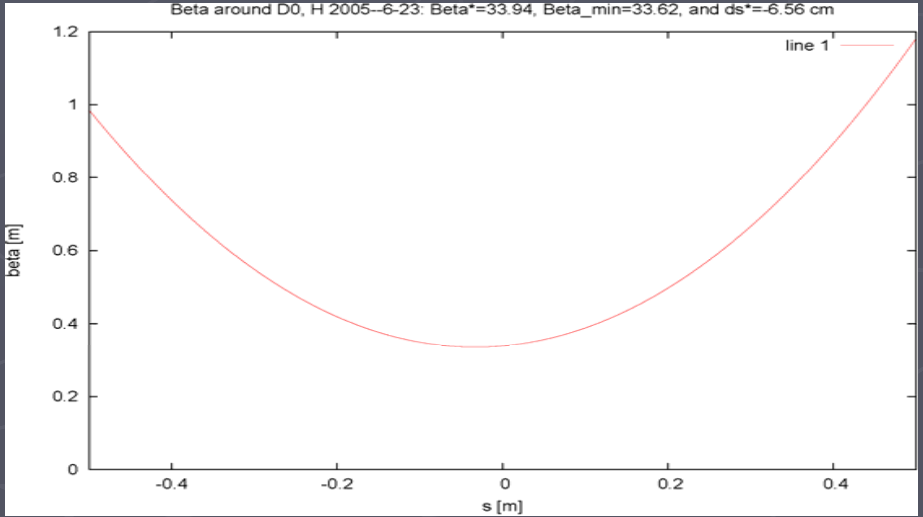
II. β* Measurements in Tevatron
2. Let's Try!

- A data set and results:



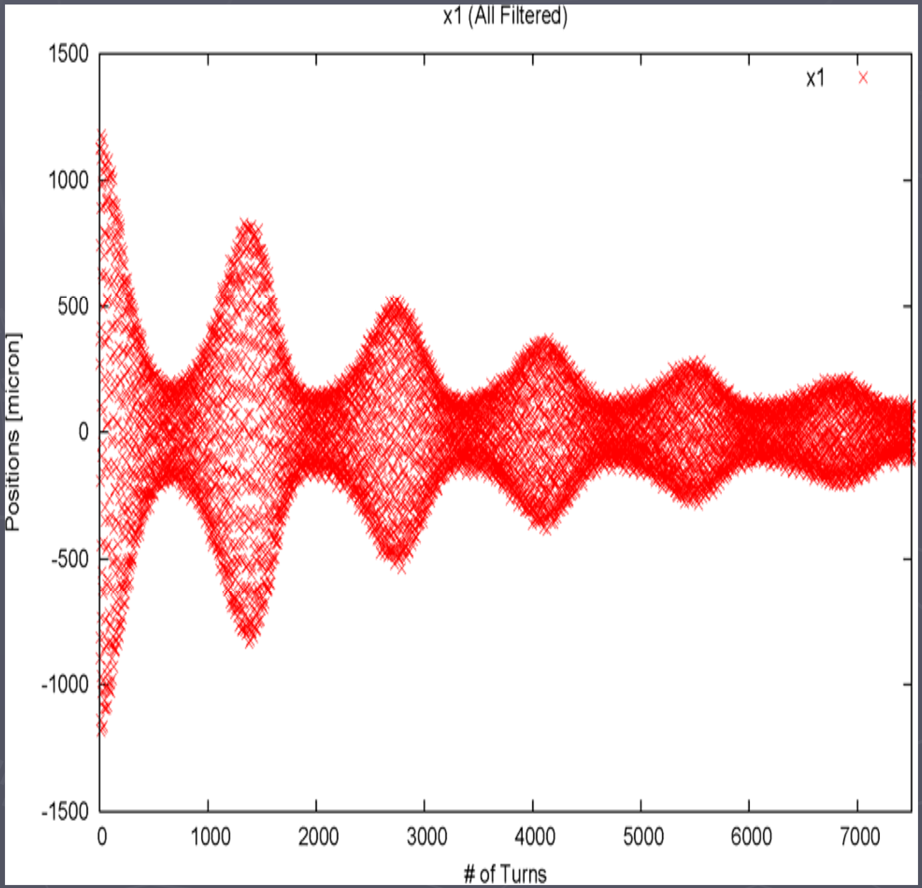
Data by Yuri

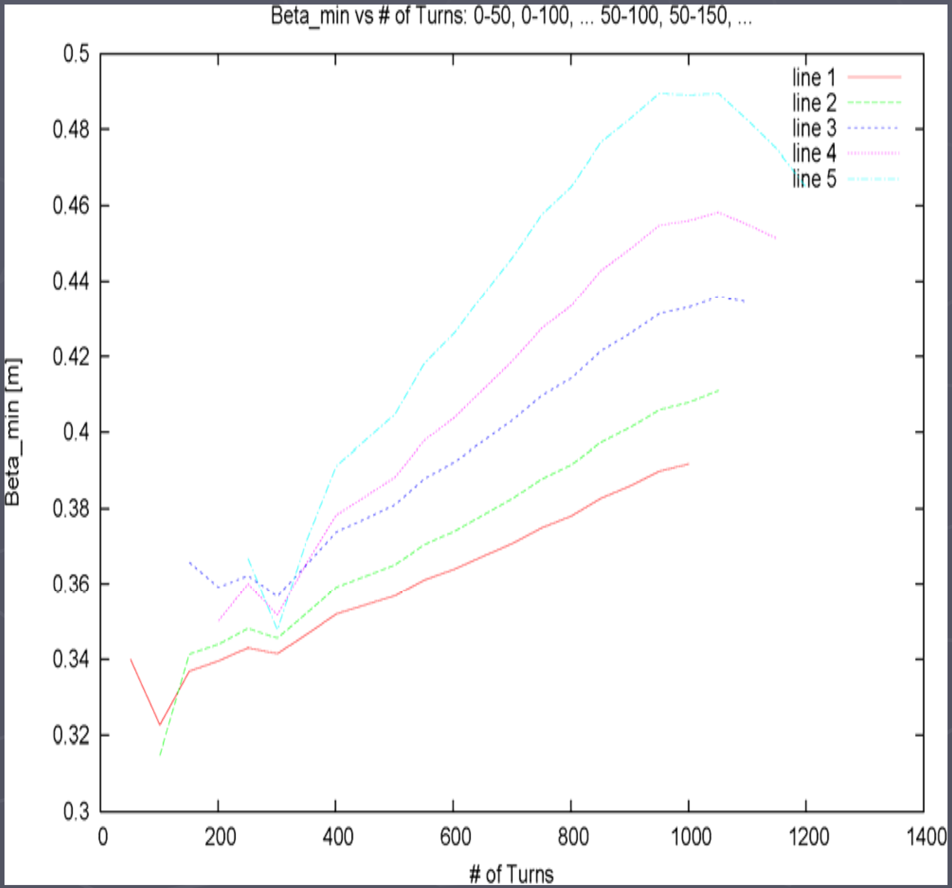




II. β* Measurements in Tevatron – 3. Issues
a. Decoherence

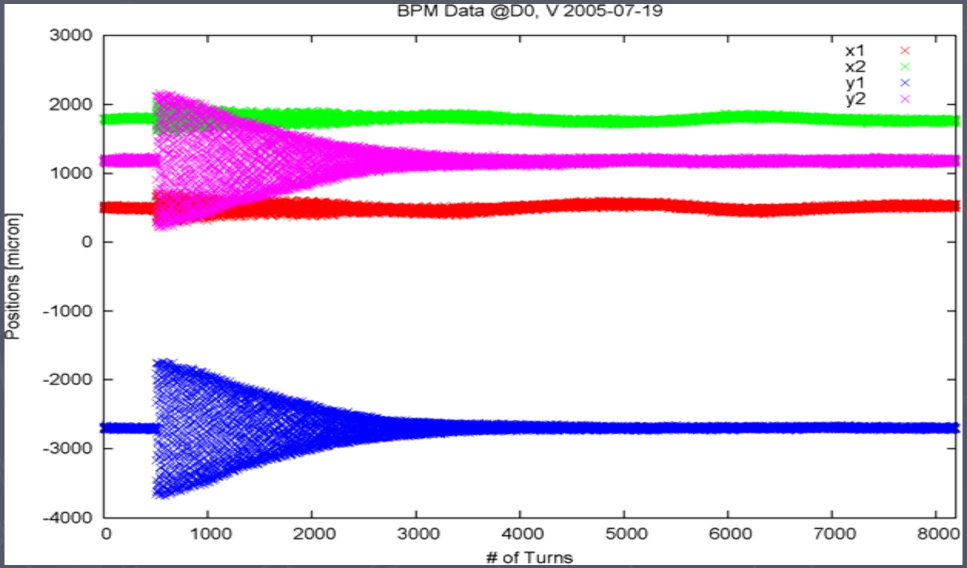
- How Many Turns to Take the Average?
  (= How Fast Decoherence Messes Data?)

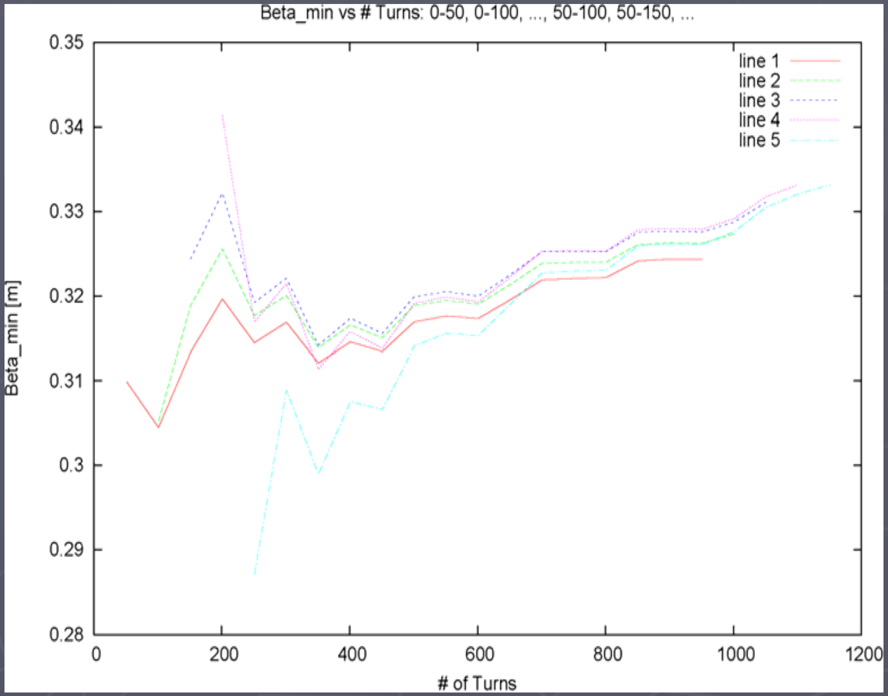


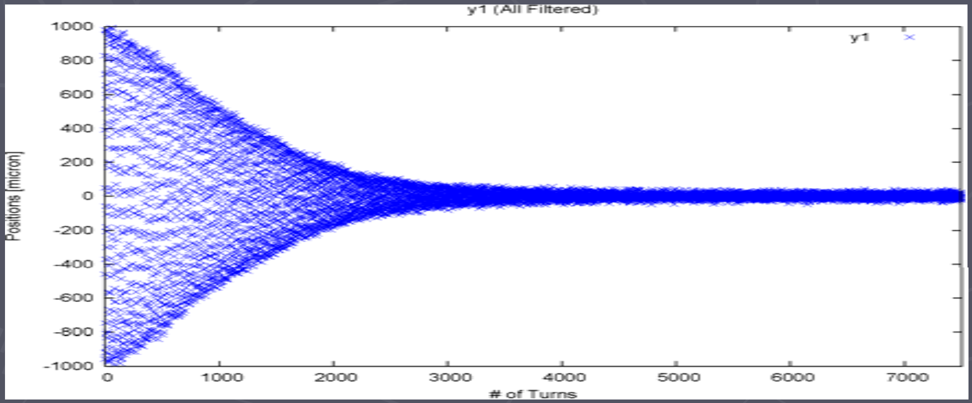


II. β* Measurements in Tevatron – 3. Issues a. Decoherence

- Another data set.





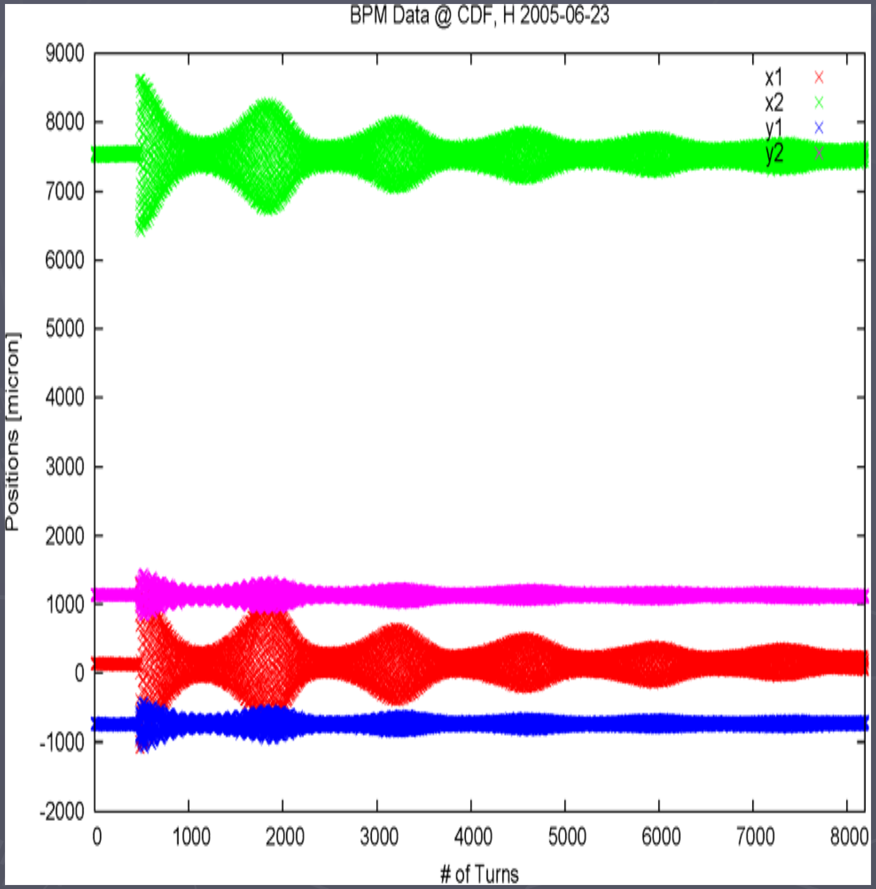


Data by Eliana

- Depends on how beams decohere but only a few 100 seems to be the safe.
- Why AC Dipole maybe good!

II. β* Measurements in Tevatron - 3. Issues
b. Nonlinearity in BPM Signals

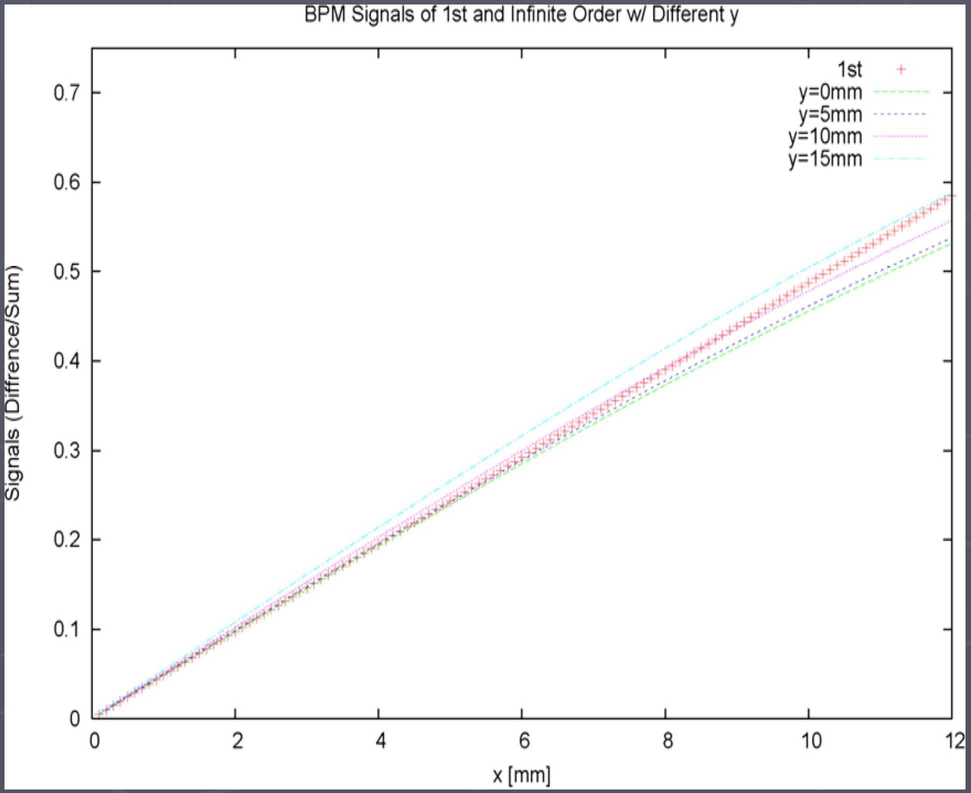
- Huge x-offset @ CDF:



Data by Yuri

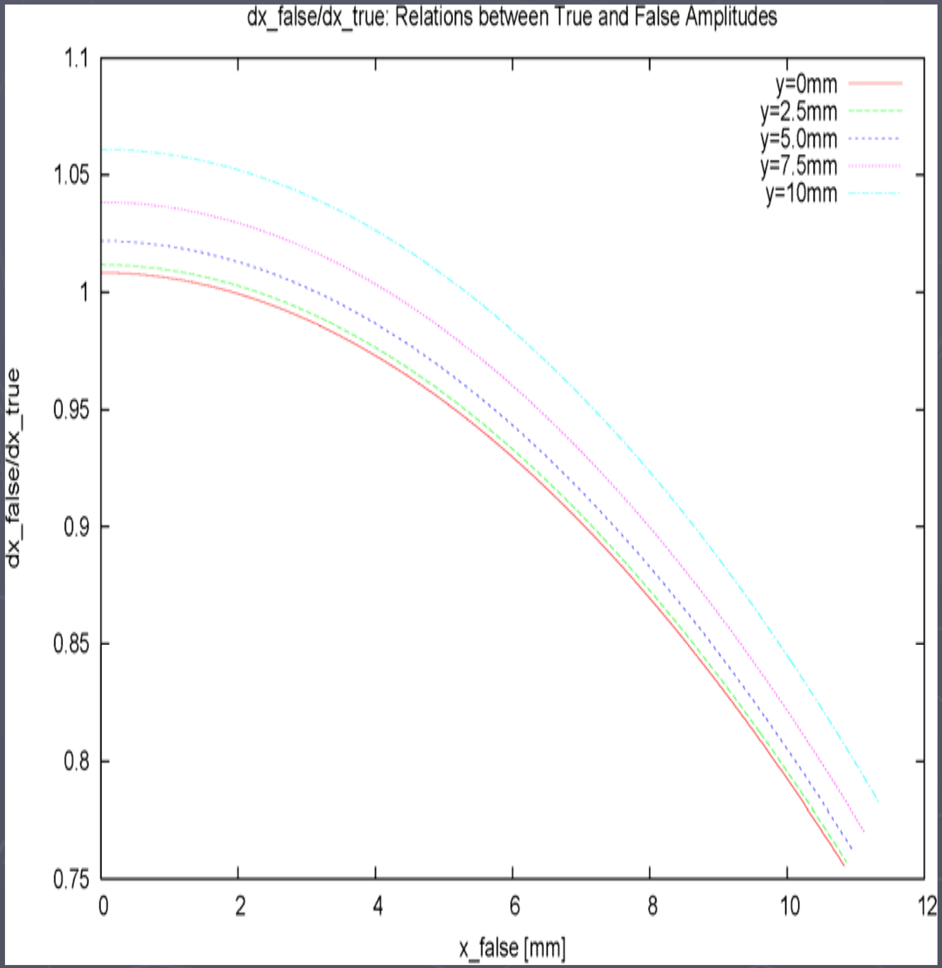
- Nonlinearity in BPM Signals:

$$\frac{I_A - I_B}{I_A + I_B} = (\cdots)\, x/b - (\cdots)(x/b)^3 + (\cdots)\, x/b\,(y/b)^2 + \ldots$$

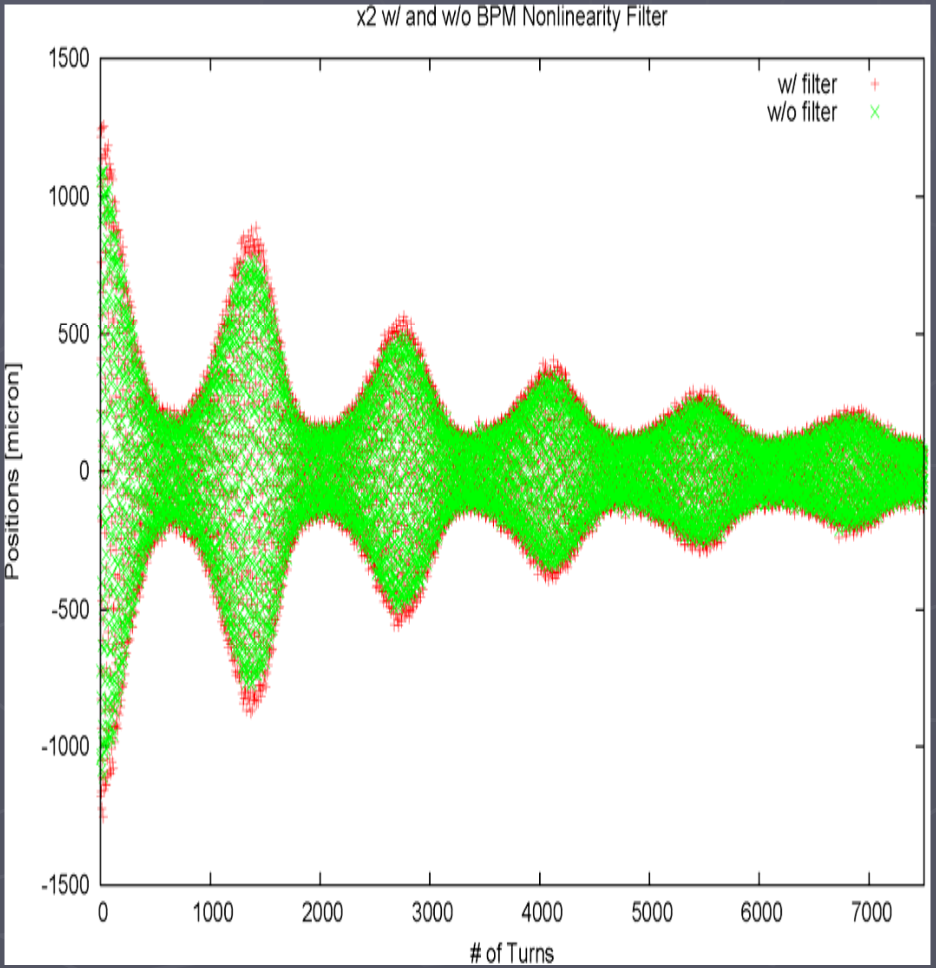


II. β* Measurements in Tevatron - 3. Issues b. Nonlinearity in BPM Signals

- How amplitudes change?

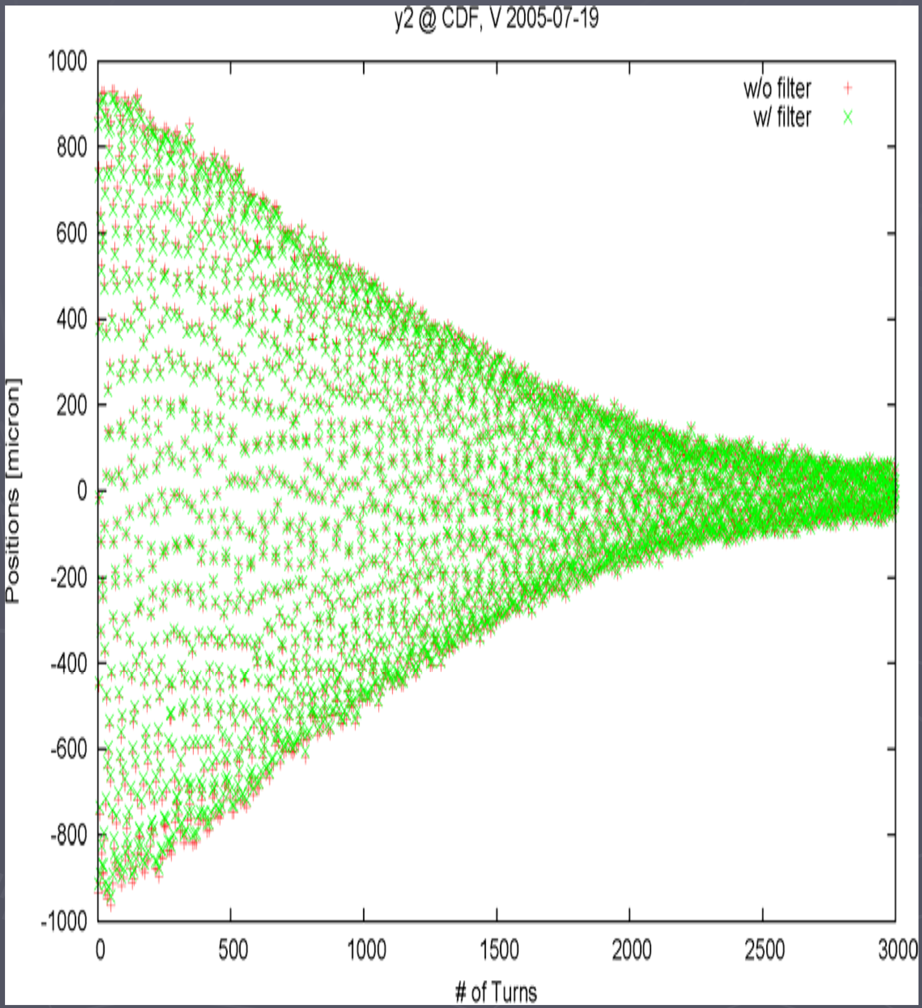


- Before & After Filtering.

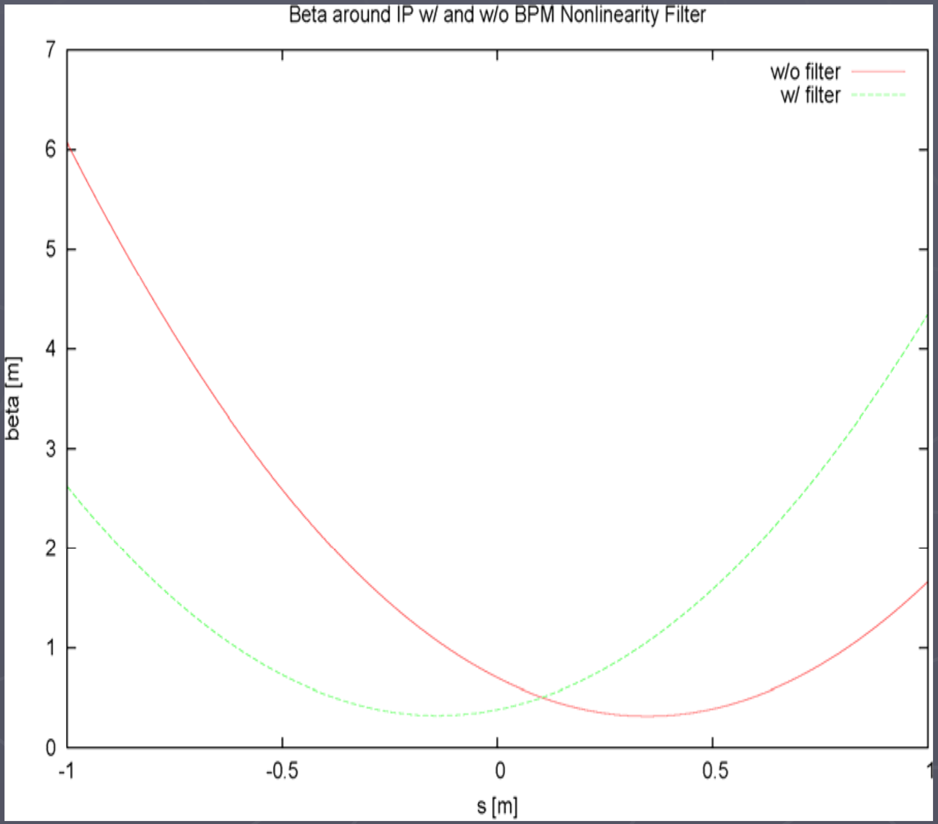


II. β* Measurements in Tevatron - 3. Issues b. Nonlinearity in BPM Signals

- Other Type of Nonlinearity



- Effects on β* and Etc:



- β^*=69.9cm → 38.2cm
- β_{min}=31.6cm → 32.2cm
- Δs^*=34.8cm → -13.9cm

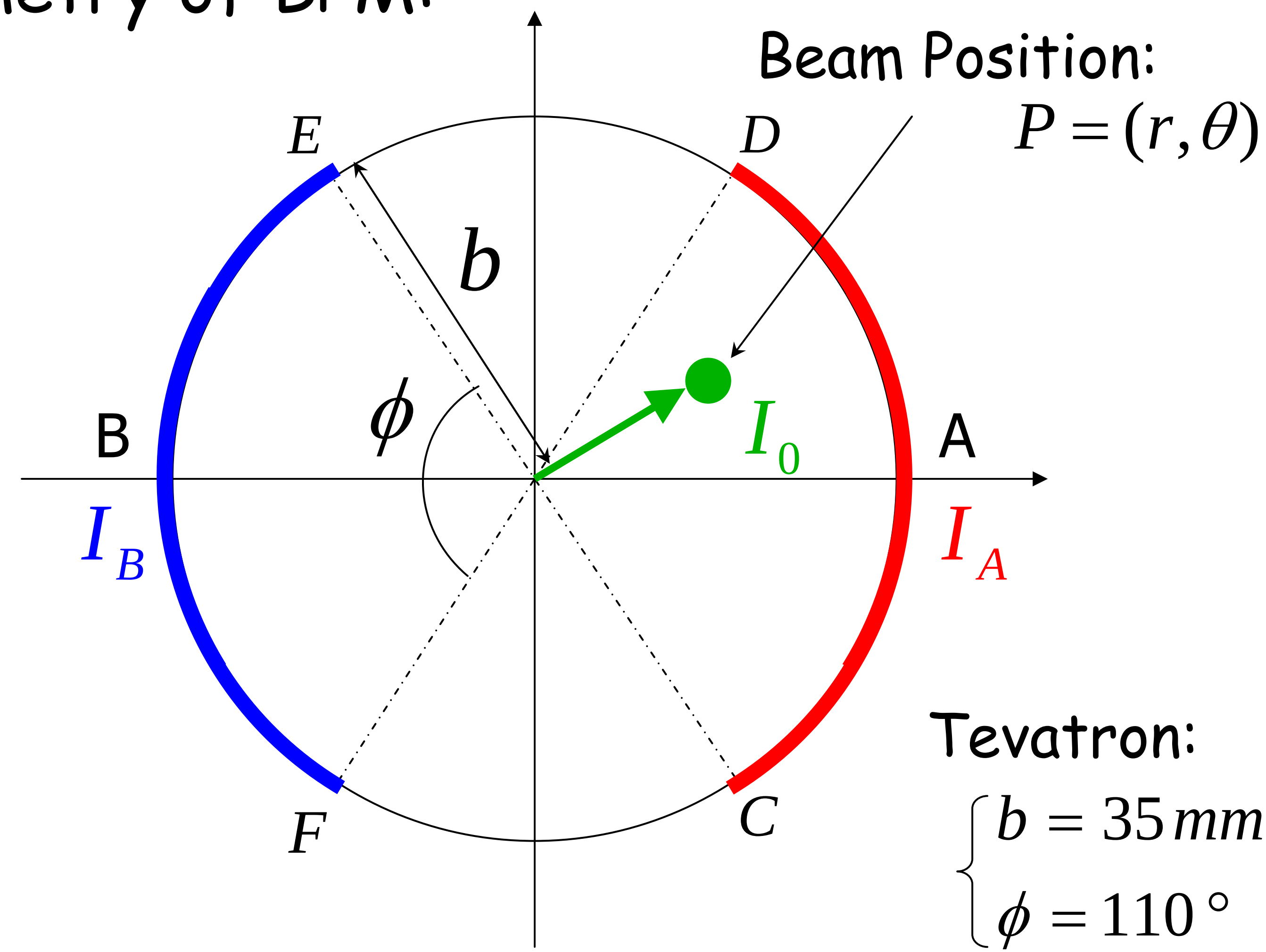
II. β* Measurements in Tevatron
4. Conclusions and Future Projects

- Conclusions:
  - The analysis seems working OK.
  - For the average, only a few hundred turns seems safe.
- From now…
  - Apply to study couplings.
  - Install the system into MCR.
  - A "REAL" beam study (take data for this analysis) to control couplings, chromaticity, and beam-beam.
  - A little more (personal) studies about decoherence and BPM.

III. Appendix: Geometry of BPM Signals

III. Appendix:

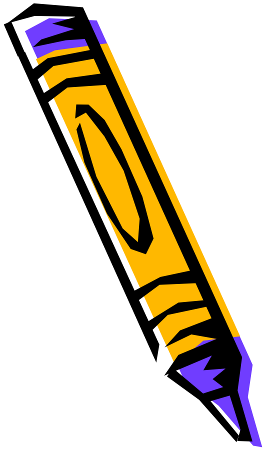
- Geometry of BPM:



Tevatron:

$$\begin{cases} b = 35\,mm \\ \phi = 110^\circ \end{cases}$$

III. Appendix:



- In infinite order…

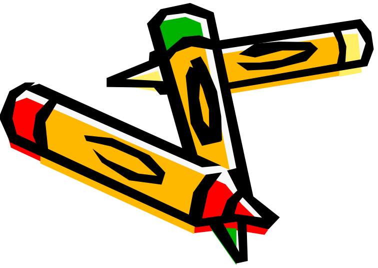
$$\frac{I_A}{I_0} = \frac{\phi}{2\pi}\left[1 + \sum_{n=1}^{\infty}\frac{4}{n\phi}(r/b)^n \cos(n\theta)\sin(n\phi/2)\right]$$

$$\frac{I_B}{I_0} = \frac{\phi}{2\pi}\left[1 + \sum_{n=1}^{\infty}\frac{4}{n\phi}(-r/b)^n \cos(n\theta)\sin(n\phi/2)\right]$$

- After a little bit of manipulation…

$$\frac{I_A}{I_0} = \frac{\phi}{2\pi}\left[1 + \frac{2}{\phi}\left(\arctan\frac{r\sin(\phi/2+\theta)}{b - r\cos(\phi/2+\theta)} + \arctan\frac{r\sin(\phi/2-\theta)}{b - r\cos(\phi/2-\theta)}\right)\right]$$

$$\frac{I_B}{I_0} = \frac{\phi}{2\pi}\left[1 - \frac{2}{\phi}\left(\arctan\frac{r\sin(\phi/2+\theta)}{b + r\cos(\phi/2+\theta)} + \arctan\frac{r\sin(\phi/2-\theta)}{b + r\cos(\phi/2-\theta)}\right)\right]$$



Looks complicated…

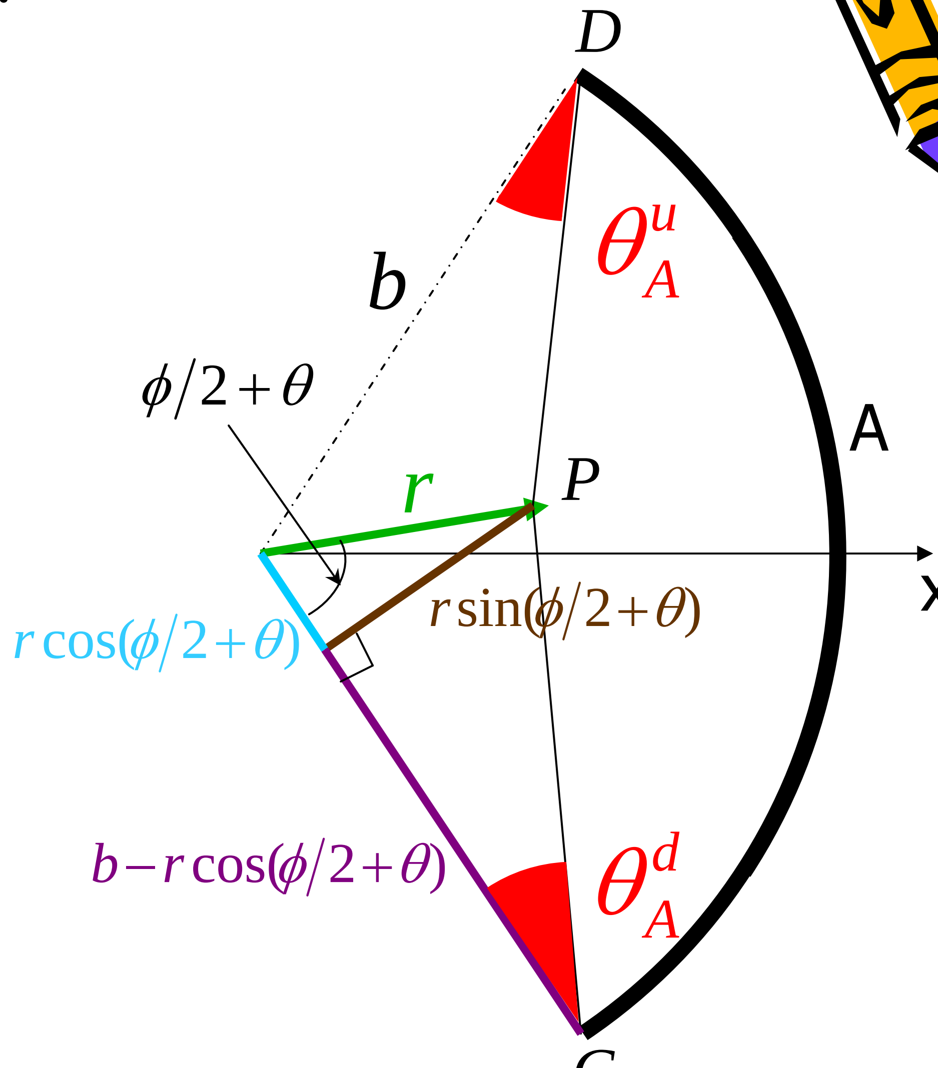
III. Appendix:

- They have simple geometrical meanings!
- Let's see the 1st term:

$$\theta_A^d \equiv \arctan\frac{r\sin(\phi/2+\theta)}{b-r\cos(\phi/2+\theta)}$$

- *Also introduce θ^u_A, θ^u_B, and θ^d_B similarly.*

Then…



III. Appendix:

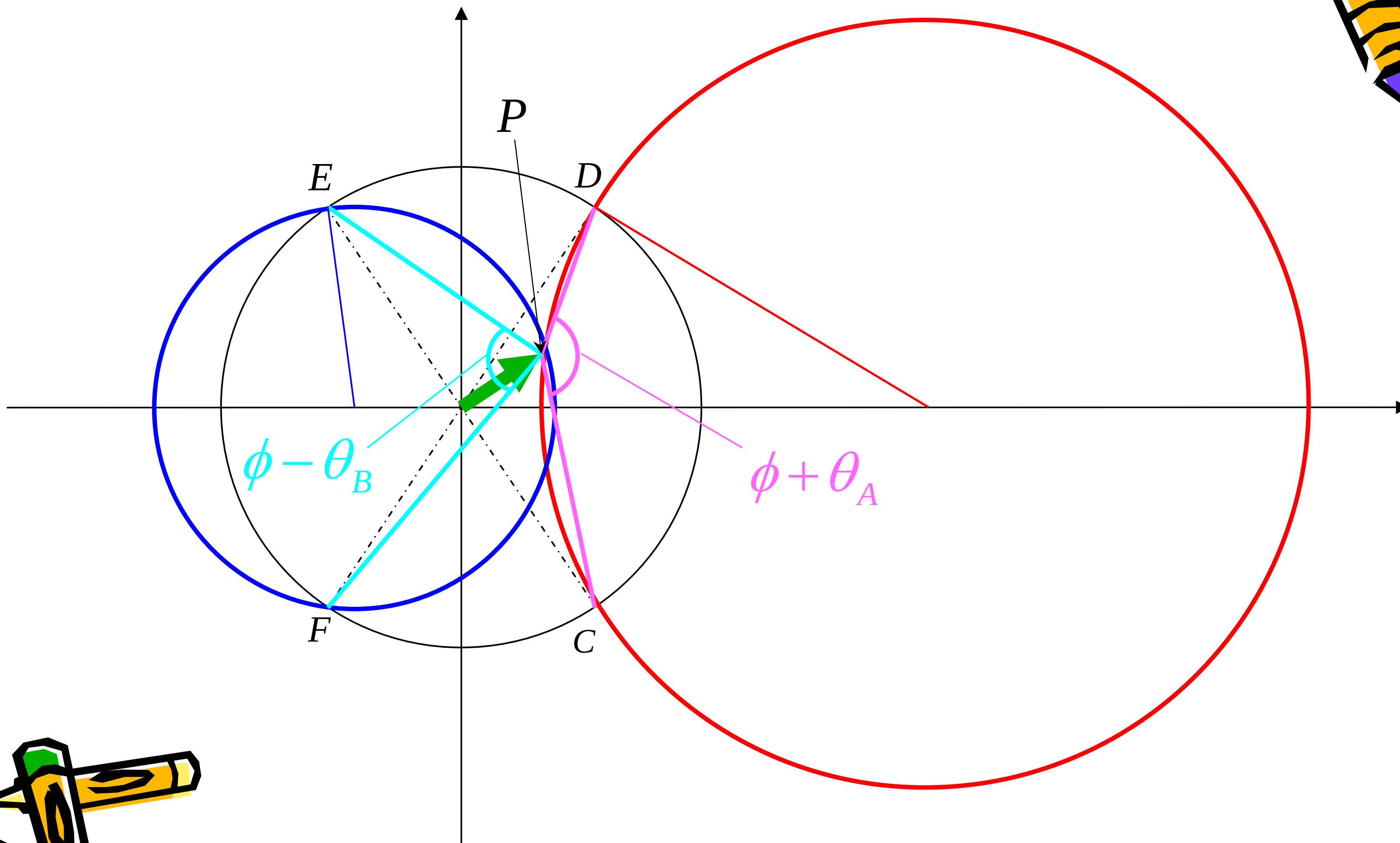
$$\frac{I_A}{I_0}=\frac{\phi}{2\pi}+\frac{\theta_A^d+\theta_A^u}{\pi}\equiv\frac{\phi}{2\pi}+\frac{\theta_A}{\pi}\qquad \frac{I_B}{I_0}=\frac{\phi}{2\pi}-\frac{\theta_B^u+\theta_B^d}{\pi}\equiv\frac{\phi}{2\pi}-\frac{\theta_B}{\pi}$$

- Measuring I_A/I_0 (I_B/I_0) is equivalent to specify the circle passing points PCD (PEF).
- The beam is at one of intersections.
- By solving the intersection problem…

$$x=\frac{\frac{b}{2}\sin\phi\sin\left[\pi\frac{I_A-I_B}{I_0}\right]}{\cos\frac{\phi}{2}\cos\left[\pi\frac{I_A-I_B}{I_0}\right]-\cos\frac{\phi}{2}\cos\left[\pi\frac{I_A+I_B}{I_0}\right]+\sin\frac{\phi}{2}\sin\left[\pi\frac{I_A+I_B}{I_0}\right]}$$

Infinite order!

III. Appendix



III. Appendix

- Remarks:
  - The approximation $(I_A+I_B)/I_0 \approx 2\varphi/2\pi$ recovers the linear relation of x and $(I_A-I_B)/(I_A+I_B)$.
  - For practical purposes, need to measure I_0 (and it is not easy).
  - If possible, how δI_0 affects δx? (Proceeding)
  - What happens if $\varphi=\pi/2$? (Proceeding)

References

I. AC Dipole
   - Search “Mei Bai & AC Dipole”.

II. β* Measurements in the Tevatron
   - M. Syphers, Beams-doc-1088 and 1880.

III. Appendix
   - R. Kutschke, Beams-doc-1893-v3

- Web Page:
   - /home.fnal.gov/~ryoichi/

The End

Thank you!