4th Meeting of the LHC Beam Cleaning Study Group 7.11.2001

Present: *R. Assmann (chairman), H. Burkhardt, G. Burtin, B. Dehning, C. Fischer, E. Gschwendtner, J.B. Jeanneret, R. Jung, V. Kain, R. Schmidt, J. Wenninger*

1) LHC Orbit Feedback (J. Wenninger)

J. Wenninger presented a detailed study of the LHC orbit feedback. The presentation is appended in the PDF version of the minutes and is available on our web site. Jörg pointed out that the cold correctors are too slow for a fast feedback. They can run at a maximum of 1 Hz. The warm correctors are much faster, allowing to run at 10 Hz, maybe at 20 Hz (they ramp to full current in about 0.5 s). Taking into account the orbit smapling (10 Hz) and the response delays (up to 125 ms) a global orbit feedback with 0.2-0.5 Hz can be envisaged. A local feedback could run at about 1 Hz, if needed. The bandwidth could be increased to 5-10 Hz by installing more warm correctors, by increasing the orbit sampling (to 20 Hz), and by reducing the delays in response. Jörg pointed out that the need fro such a fast feedback should be demonstrated. He calculated the effect from snapback of random B1. The resulting orbit change of 1 mm can be corrected by 900 nrad rms kicks. There is no shortage of corrector strength.

Further questions on orbit stability were discussed, centering on high frequencies (e.g. motion at 50 Hz), the time-dependent orbit during snapback, and the interaction of local orbit feedbacks with the machine protection requirements of the collimation system.

2) Preliminary Beam Loss Studies (V. Kain)

V. Kain presented her first results on beam loss studies, done together with R. Schmidt as a technical student. The presentation is appended in the PDF version of the minutes and is available on our web site. Verena introduced the physic implemented in her tracking program. The program allows tracking of a beam distribution in 1D during a magnet quench. Verena showed that, depending on the time scales, the particles must be tracked or an adiabatic change of orbit can be assumed. She calculated the maximum orbit distortion for quenching of different dipoles, showing that the orbit can reach 9.5 σ for certain phase advance conditions. This means that the collimation system does protect efficiently against adiabatic orbit changes in one phase, however, not in the orthogonal phase. Further work is required.

3) Survey, Collective Effects and Thermal Studies (J.B. Jeanneret)

J.B. Jeanneret reported on three meetings. The presentation is appended in the PDF version of the minutes and is available on our web site. A meeting with J.P. Quesnel, C. Fischer and himself addressed the survey and mounting accuracy for the collimators. The initial survey accuracy will be 150 μm, degrading to 200 μm after one year of operation. J.B. Jeanneret also had a meeting with D. Brandt and L. Vos on collective effects. A tapering will be needed, adding about 0.2 m to the length of the jaws (0.2 m primary, 0.5 m secondary). This will require a change in the layout of the cleaning insertions. An RF contact might be needed on the collimator jaws. L. Vos and D. Brandt also questioned the vacuum ports on the collimator tank. Further work is required. Finally, J.B. Jeanneret reported on a meeting with T. Kurtyka, R. Valbuen, C. Fischer, R. Jung, and himself. They discussed possible support on thermal studies for the collimators. There was no result and further discussions are needed.

4) Next meeting

The next meeting remains to be announced, due to the BI review on November 19th.

LHC Orbit FB

J. Wenninger

Work done in collaboration with T. Wijnands

- Some feedback concepts
- Magnets & power converters for feedback
- Sampling, delays…
- IR layout
- Conclusion

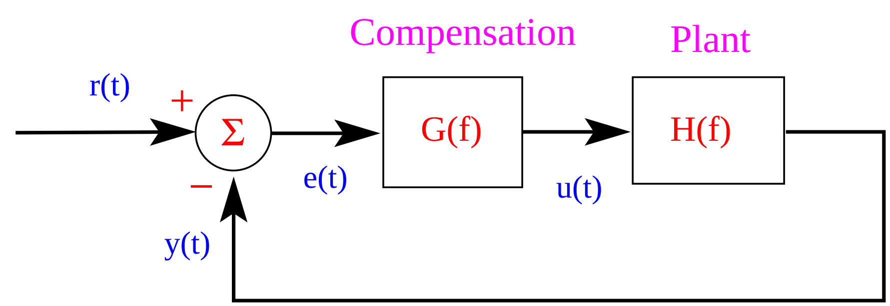
The scene

The role of the orbit feedback is to maintain the orbit as close as possible to a given reference. The starting point is :

- A good CO has already been established by the operation crews.
- The collimators have been positioned & adjusted around that CO.

Feedback I

The key roles of a feedback :



- Tracking of a reference r(t).
- Disturbance rejection (noise,…)

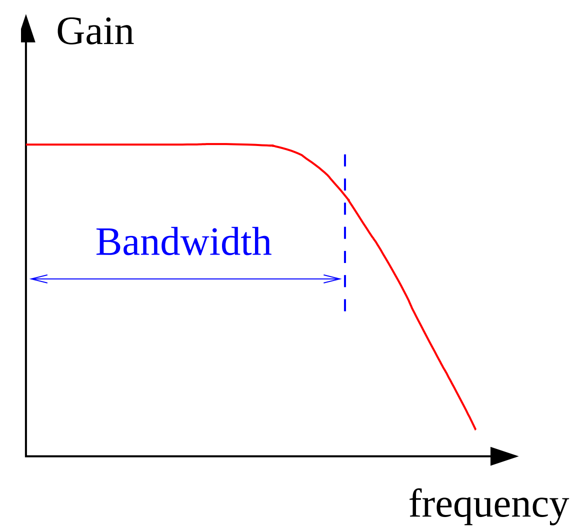
A classical feedback acts on a plant (car, plane..) with some internal dynamics represented by a transfer function H(f). The dynamics is the key to the design of the compensation G(f) which evaluates the actuator settings u(t) (for us the corrector magnets).

In accelerators there is (in general) almost no dynamics, except for magnets and power converters. The design is mostly driven by the noise i.e. disturbance rejection, because usually one chooses very fast actuators (correctors) → this is somewhat different for LHC !

Feedback II

Characteristics of the feedback

- Bandwidth BW
- Gain
- Robustness
- …



For a digital feedback, the signal sampling frequency f_s should be significantly larger than the desired BW :

$$f_s \approx (6 - 30)\ BW$$

Digital Control

Many designs for control loops with sampling interval T.

The classical way is to use a PID controller :

$$u_k = K \left(e_k + (T/T_I) \Sigma e_k + (T_D/T) (e_k - e_{k-1}) \right)$$ at step k..

Proportional — **I**ntegral — **D**ifferential

K, T_I and T_D are adjusted to obtain a good FB response.

A somewhat different but attractive and powerful design is based on a ***State-Space formalism*** which is used as a standard in ~ all SLAC digital feedback loops.

Under investigation (with help of EPFL…)

PC bandwidth

Consider a Power Converter which should produce a current @ a frequency f :

$$I(t) = I_0 \sin(2 \pi f t)$$

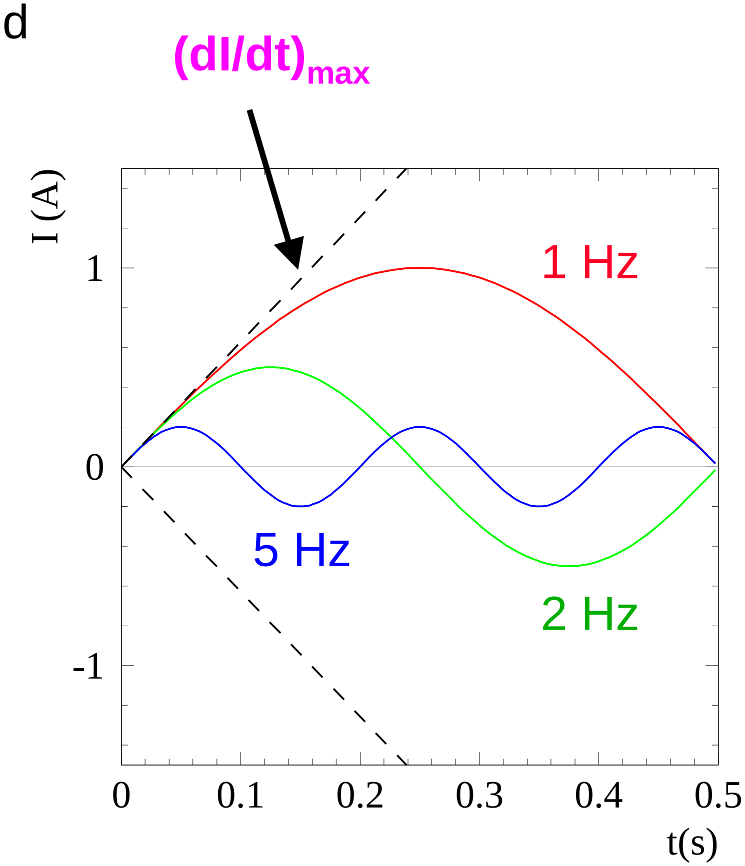
The peak current derivative is

$$(dI/dt)_{peak} = \pm 2 \pi f I_0$$

If the PC is limited by $(dI/dt)_{max}$, I_0 cannot exceed

$$I_0 = (dI/dt)_{max} / (2 \pi f)$$

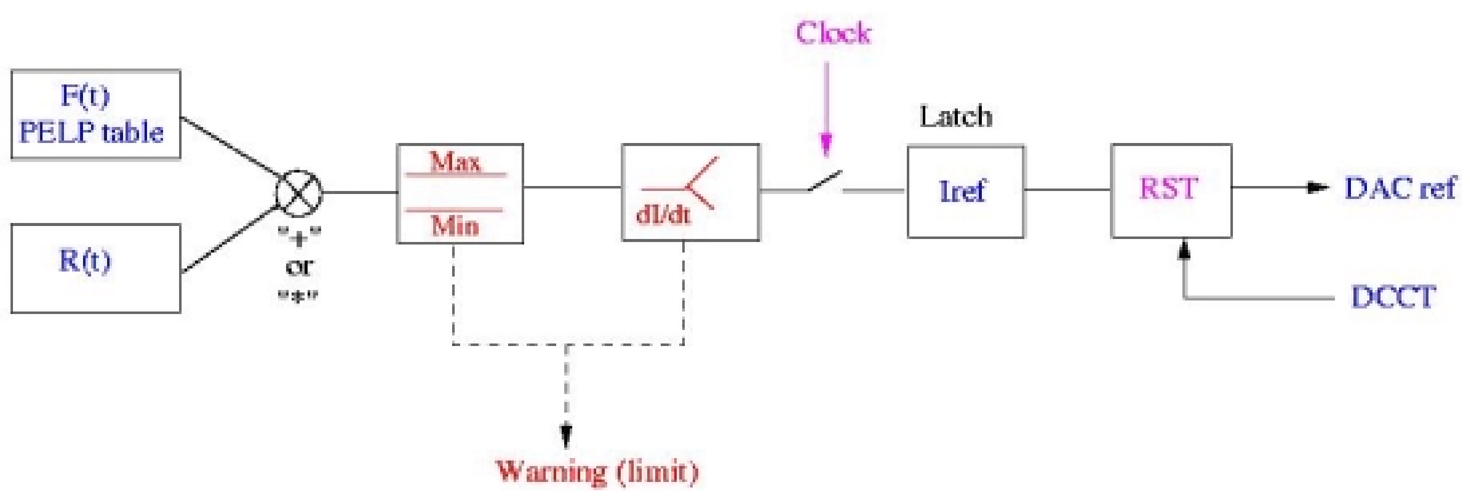
… or I(t) will be distorted (delays…)



PC controllers

The PC digital controllers :

- table [F(t)] + real time [R(t)] inputs.
- inputs are clipped according the I and dI/dt limits.
- clipped inputs are sampled every 1 to 500 ms (latch).
- the current loop runs at up to 10 Hz.
- internal delay for R(t) ~ 10-20 ms (depends on PC type).



Cold correctors I

Component	Parameter	Value
Magnet (MCBH/V)	L	7 (H)
	R	20 (mΩ)
	τ = L/R	230 (s)
	$(BL)_{nom}$	1.9 (Tm)
	I_{nom}	55 (A)
	θ_{nom} @ 450 GeV	1.26 (mrad)
	θ_{nom} @ 7 TeV	81 (μrad)
PC	I_{max}	± 60 (A)
	U_{max}	± 8 (V)
PC ⊕ Magnet	$(dI/dt)_{max}$	0.9 (A/s)

Cold correctors II

The cold correctors have very long time constants τ corresponding to a natural (open-loop) frequency of :

$f_{ol} = 1 / (2 \pi \tau) = 0.5$ mHz → Difficult to run @ 1 Hz or more → Need a large voltage ! (L dI/dt)

At 1 Hz :

$\max(I_0) = 0.1$ A → kicks of 2 μrad @ 450 GeV
0.1 μrad @ 7 TeV

At 7 TeV a single corrector can move the orbit by ~ 10 μm (β = 100 m)

NB : the DISS orbit correctors have similar characteristics (τ,…)

Warm correctors I

Component	Parameter	Value
Magnet	L	~ 20 (mH)
	R	~ 25 (mΩ)
	$\tau = L/R$	~ 0.8 (s)
	$(BL)_{nom}$	2.2 (Tm)
	I_{nom}	500 (A)
	θ_{nom} @ 450 GeV	1.46 (mrad)
	θ_{nom} @ 7 TeV	94 (μrad)
PC	I_{max}	± 600 (A)
	U_{max}	± 40 (V)
PC ⊕ Magnet	$(dI/dt)_{max}$	1250 (A/s)

Warm correctors II

The warm correctors have much shorter time constants τ corresponding to an open-loop frequency of :

$$f_{ol} = 1 / (2 \pi \tau) = \sim 0.2 \text{ Hz}$$

They will be able to run @ 10 Hz – potentially at 20 Hz…

At 10 Hz :

$max(I_0) = 20$ A → kicks of 58 μrad @ 450 GeV
3.8 μrad @ 7 TeV

At 7 TeV a single corrector can move the orbit by ~ 400 μm (β = 100 m)

Correction algorithms

The choice of the correction algorithms need not be done now. But there is some advantage of using corrections based on Singular Value Decomposition (SVD) :

- correction is extremely fast and flexible (the real number crunching is done in advance or in parallel by a dedicated process).
- can be configured to prevent building up local bumps.
- requires smaller kick strength but uses (many) more correctors than the MICADO algorithm – good with “slow” correctors !
- for local corrections, a closure must be enforced using 1 or 2 correctors on each side of the target area.

This algorithm is used with success in ~ all synchrotron light sources…

Sampling, delays

Some characteristics :

- Orbit sampling frequency of **10 Hz** → **BW < 1-2 Hz**
- Estimated delays in milliseconds (***for central FB***) :

Delay source	*Min*	*Max*
Data Acquisition	20	20
Network	2.5	25
Correction algorithm	<< 10	30
Power Converter Control	20	50
Total	52.5	125

A delay δ limits BW :
BW < ~ $1/(3\delta)$

→ **BW < ~ 6 Hz**

NB : for a frequency $1/f = 2\delta$ the correction would be 180 out of phase with the signal and drive the system into instability !

Global & local

The feedback could be split into more that one loop which could be :

- Global i.e. affecting the orbit in the whole ring.
- Local around collimation insertions → require closed corrections.

LEP experience ⊕ snapback & field decays in the LHC :

- A global orbit feedback is/will be very useful.
- This global feedback need not be ***fast*** (BW of 0.2-0.4 Hz).
- It will not differ much from a classical “measure-correct” sequence…

The global feedback could be complemented by FASTER local loops with BW of 1.0 Hz and more (?).

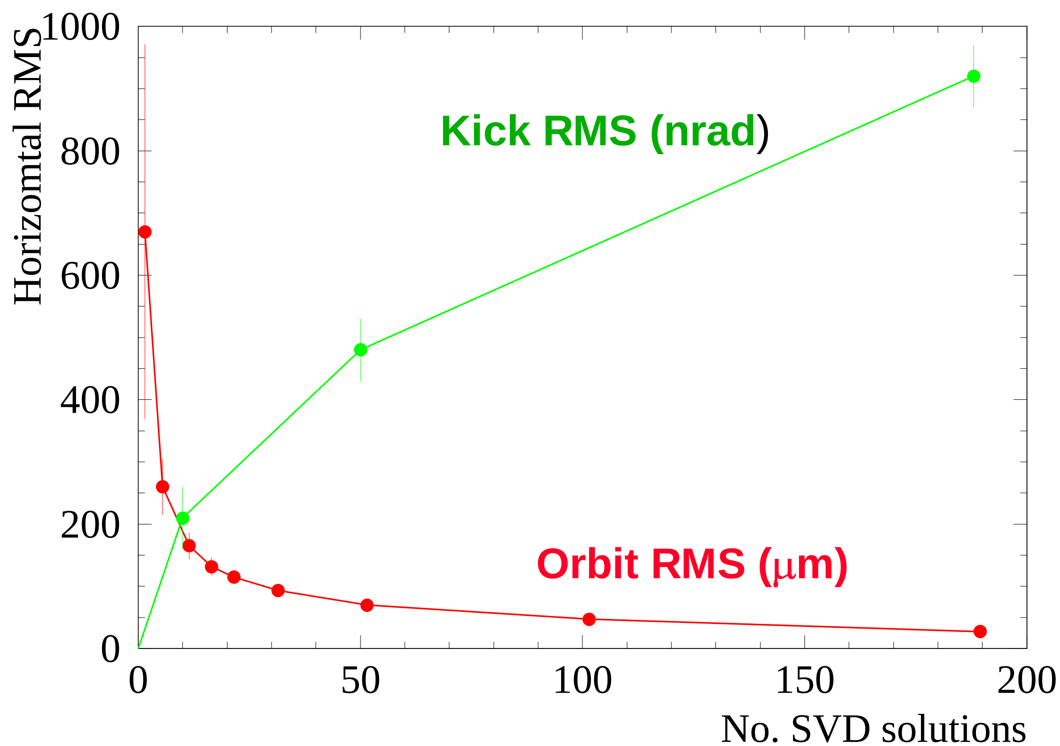
Such a frequency decoupling is a standard way to decouple the loops.

Snapback

Global correction for b1 decay of 0.75 units using only cold arc correctors.

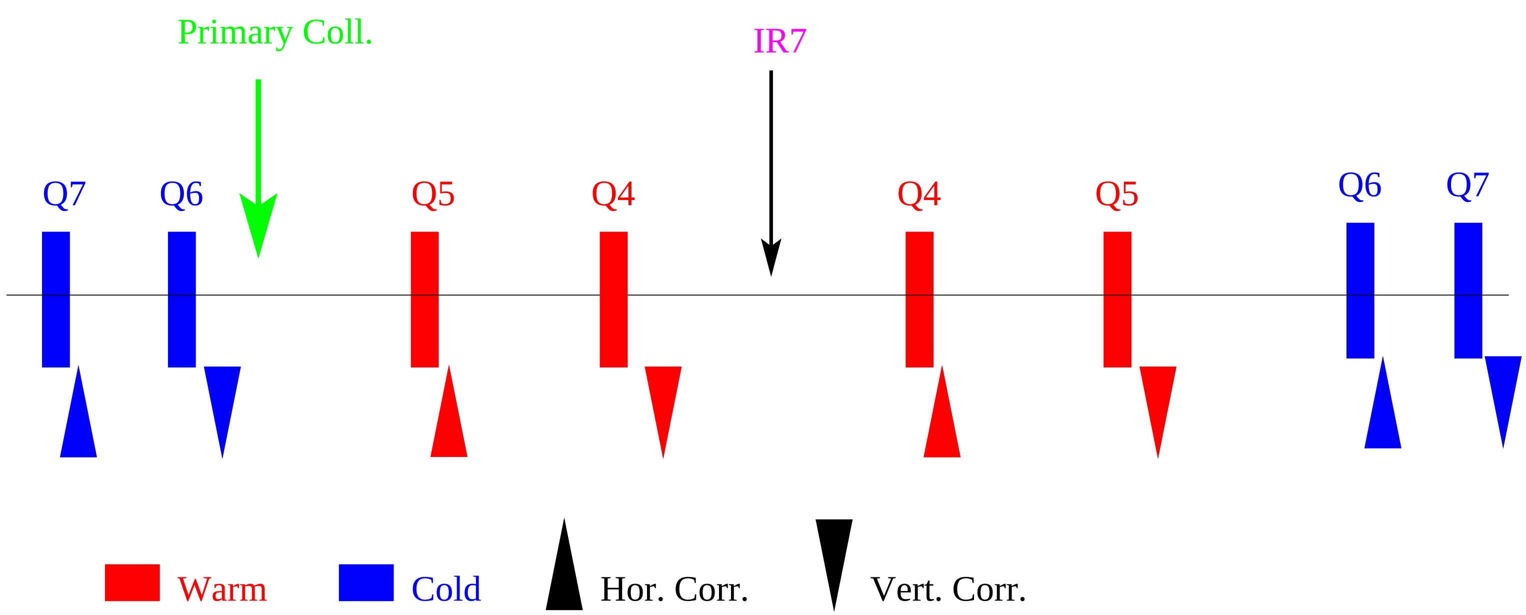
↓

Kick strengths and orbit RMS are adequate…



IR7 layout

Example for beam 1 :



→ **too few warm correctors to take advantage of their “speed” !**

Local steering

To stabilize the **angle & position @ primary collimator** :

- Need 2 correctors/plane on each side (4 corrector bump).
- We must use correctors in the cryostat of Q7 & beyond :

  → limited by speed of cold correctors !

If we could replace the cold correctors @ Q6/Q7 by warm correctors :

- Try a local steering with 4 correctors (must be closed !!).
- Steer only position @ primary using a 3 corrector bump.
- Must check if that makes any sense !

Obviously the similar limitations due to cold correctors apply for local corrections around the entire IR7 (extending into the DISS).

Summary I

With the present layouts and hardware we are limited in BW :

• by cold correctors to	**~ 1 Hz**
• by orbit sampling to	**1-2 Hz**
• by delays to	**~ 5 Hz**

We could increase the BW (to **5-10 Hz**) by :

- ***installing more warm correctors in IR3/7.***
- increasing the orbit sampling to 20 Hz or more (local ACQ).
- limiting the delays as much as possible (going local…).

to be evaluated !

Summary II

Global feedback :

- required to stabilize the orbit at injection, during snapback, ramp..
- bandwidth of 0.2–0.5 Hz is probably adequate.
- should not be a problem.

Fast local feedbacks :

- must clarify the requirements :
    - **position/angle @ primary ?**
    - **overall (local) correction over IR ?**
    - **….**
- do we need 10 Hz ?
- …

Programm for linear horizontal tracking

Motivation

- Studying failures of LHC equipment
- What happens to the beam?

Dipole Magnet Failures

due to

1. Magnet Quenches

$$\Theta(t) = \Theta_{max} - \Theta_{max} \cdot e^{-\frac{t^2}{2\sigma^2}}$$

$$\sigma \approx 200ms$$

2. Failure of the Power Converter or Power Abort

$$\Theta(t) = \Theta_{max} \cdot \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$\tau = \frac{L}{R}$$

What does the programm?

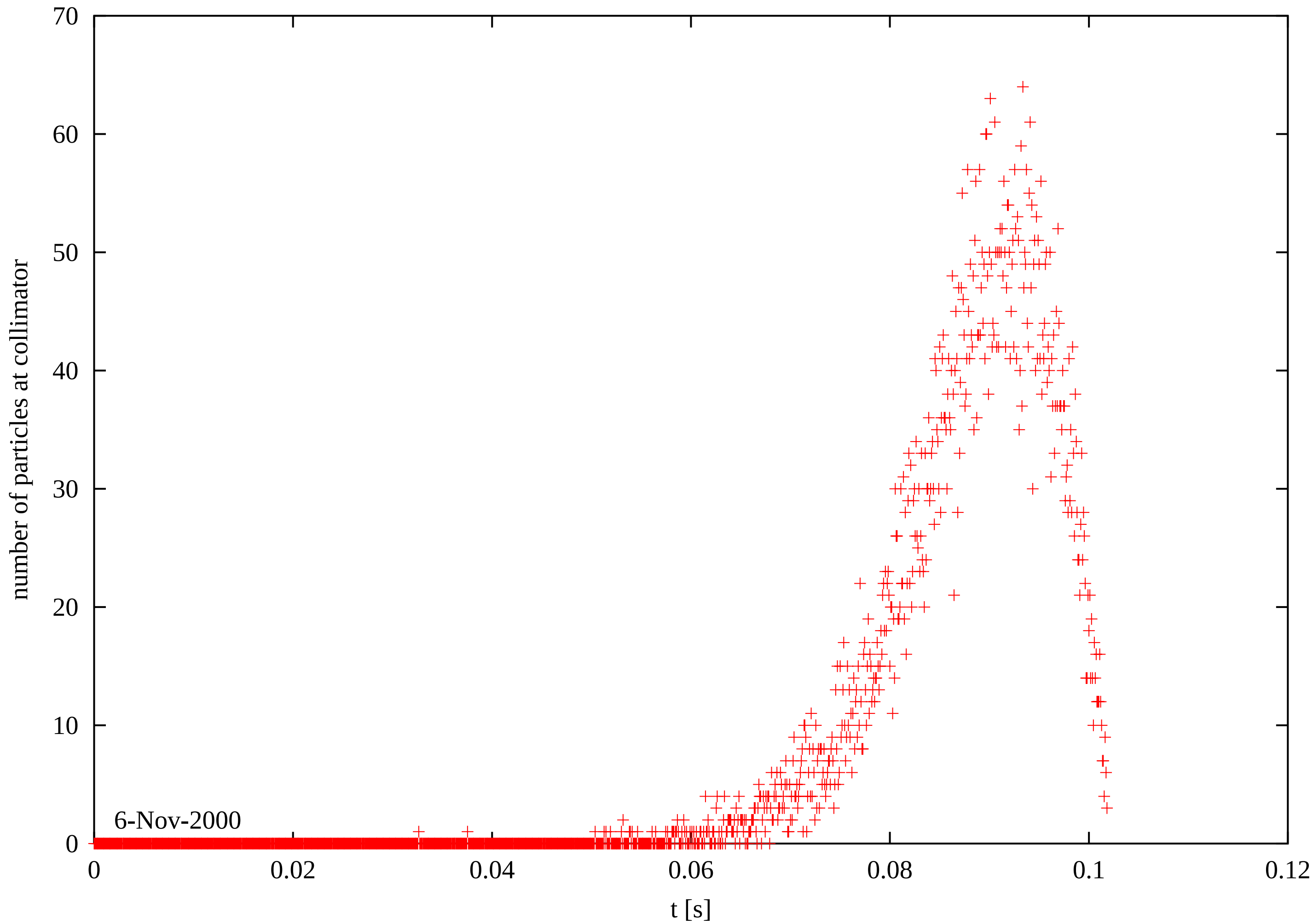
The displacement after k turns is:

$$\begin{pmatrix} x(k) \\ x'(k) \end{pmatrix} = \mathbf{M}_{k\,turns} \cdot \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} + \sum_{q=0}^{q=k} \mathbf{M}_{(k-q)\,turns} \cdot \begin{pmatrix} 0 \\ \Theta(q) \end{pmatrix}$$

The displacement due to the magnet failure is:

$$\Delta x(k) = \sqrt{\beta_{dip}\beta_{col}} \sum_{q=0}^{q=k} \sin(2\pi Q\,(k-q) + \Delta\psi)\Theta(q)$$

Beam1, Collision: Quench at D2 right of IP2, Primary Collimator in IP7



Parameters used for D2-Quench-Tracking

energy	7 TeV
emittance	0.503 nm
Q	64.310000473
σ_Θ	400 ms
$N_{particles}$	10^4
Θ_{max}	1.11 mrad

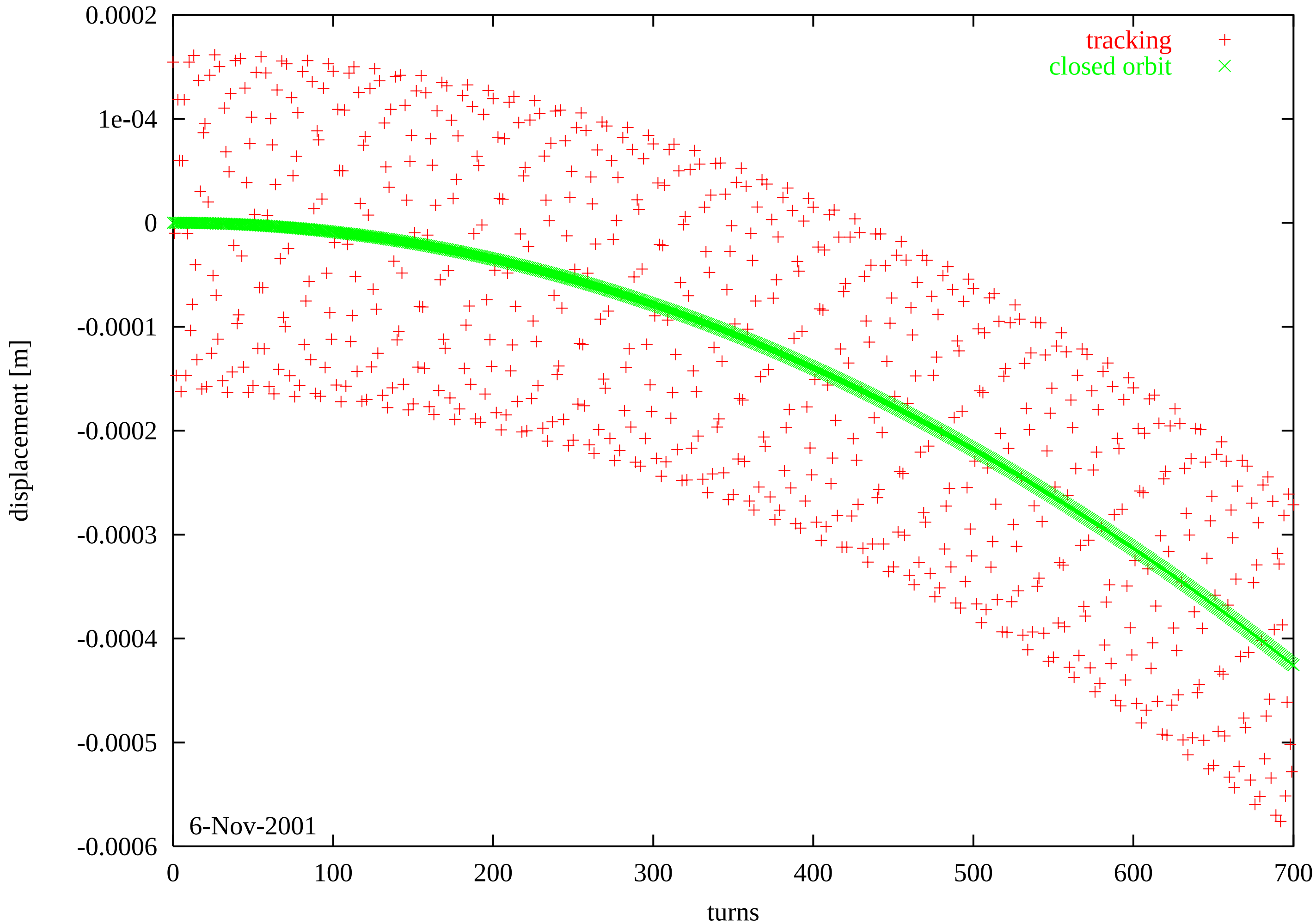
ΔB	2.742 T
l	9.45 m

$$\Theta_{max} = \frac{e}{p} \cdot \Delta B \cdot l$$

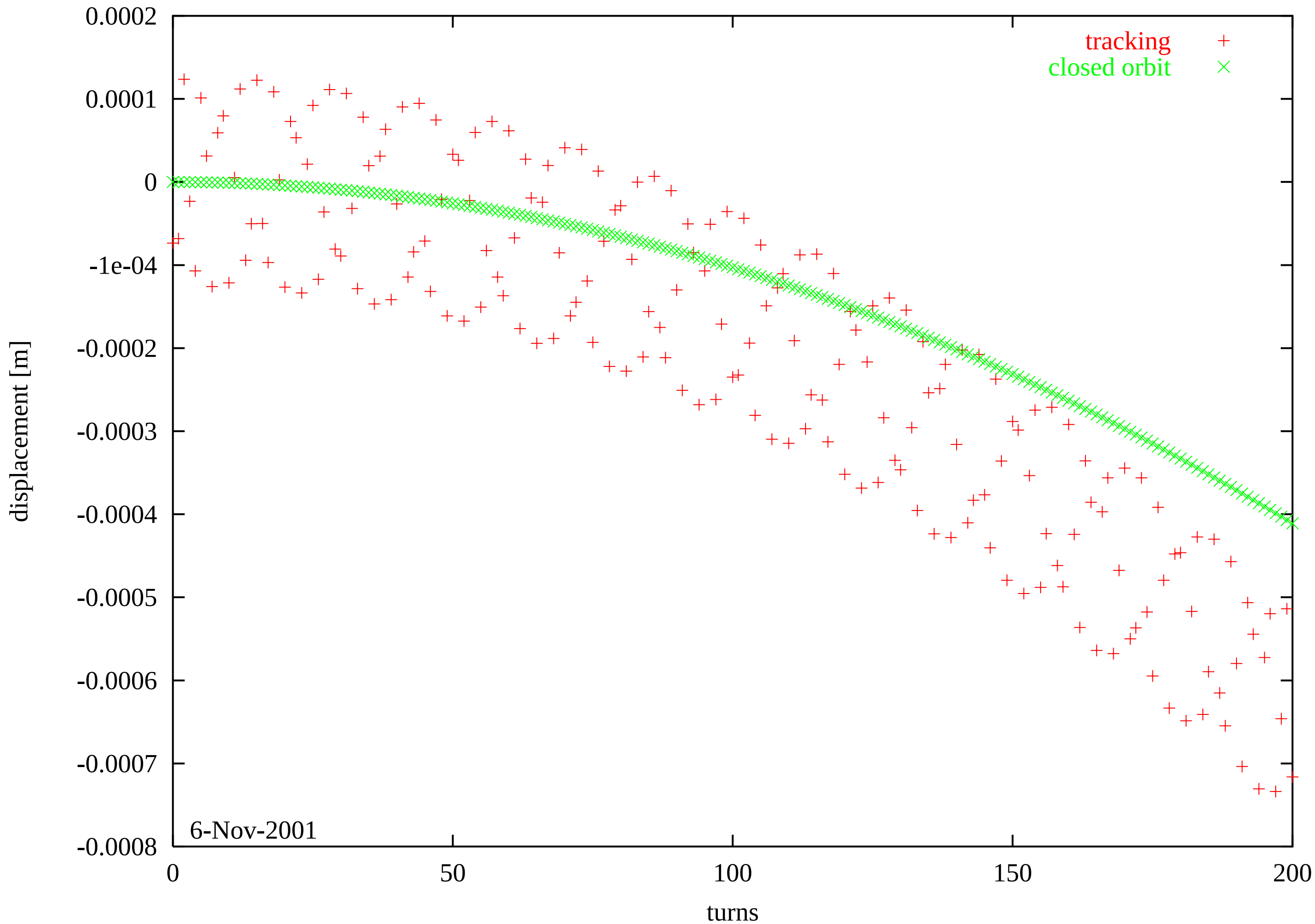
Horizontal Displacement of the Closed Orbit at Collimator-Position

$$x_{closed}(t) = \frac{\Theta(t)}{2} \sqrt{\beta_{dip}\beta_{col}} \cdot \frac{cos(\pi Q - \Delta\psi)}{sin(\pi Q)}$$

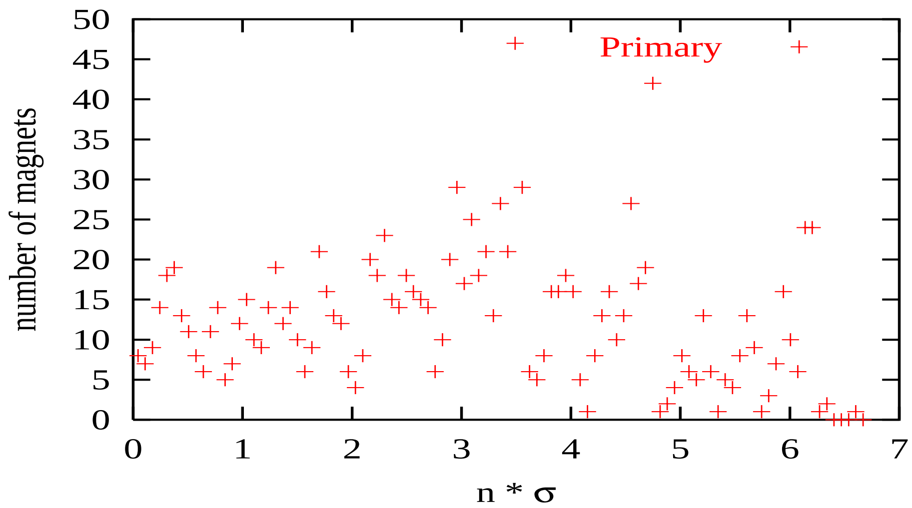
D2: It is sufficient to look at the closed orbit

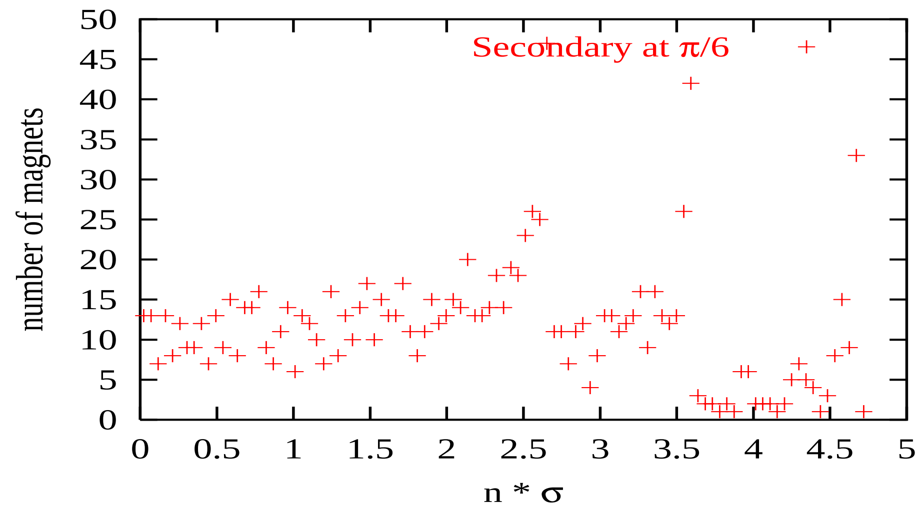


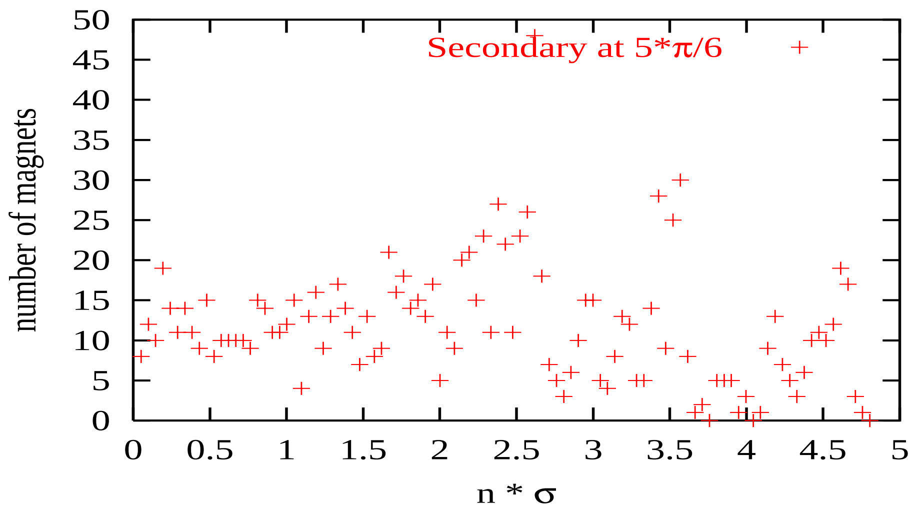
$\sigma_\Theta = 200$ ms, $\Theta_{max} = 5.11$ mrad: Tracking becomes necessary



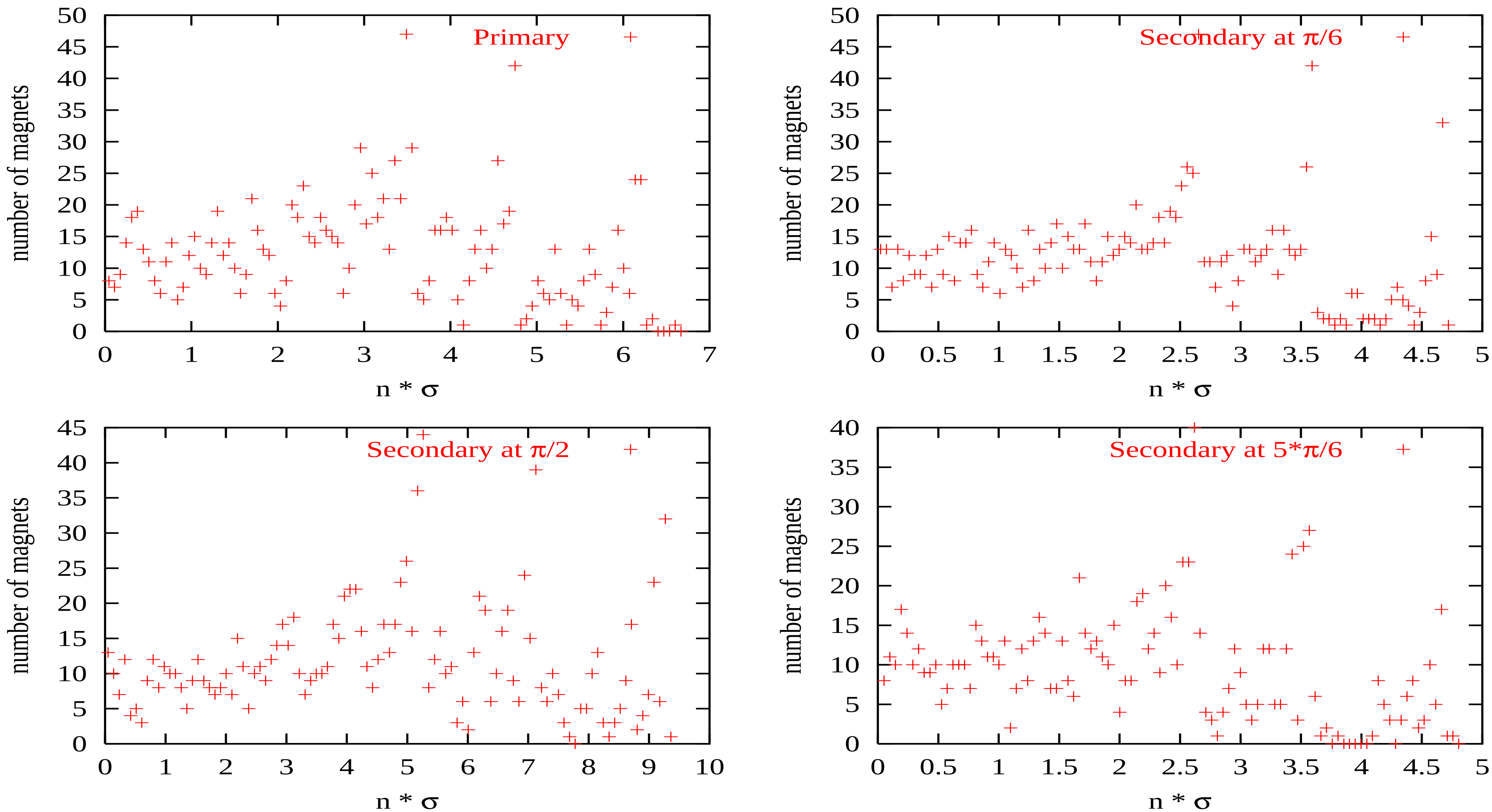
Secondary Collimators at ∼ 30° and at ∼ 150°







Secondary Collimators at $\sim 30°$, $\sim 90°$ and at $\sim 150°$



Parameters used for closed orbit–calculation at horizontal collimators at IP7, MB-magnet–Quench

energy	7 TeV
emittance	0.503 nm
Q	64.310000473
σ_Θ	400 ms
Θ_{max}	5.11 mrad

ΔB	8.33 T
l	14.3 m

total number of MB-magnets in the ring: 1232

after 360 turns: $\Theta = 1.7 \cdot 10^{-5}$ rad

Plans

- Including the vertical plane in my studies
- What happens to the beam, if there are more dipole magnet failures at the same time?

Survey,Collective effects and thermal studies

LHC coll study group

J.B. Jeanneret
CERN, Geneva, Switzerland

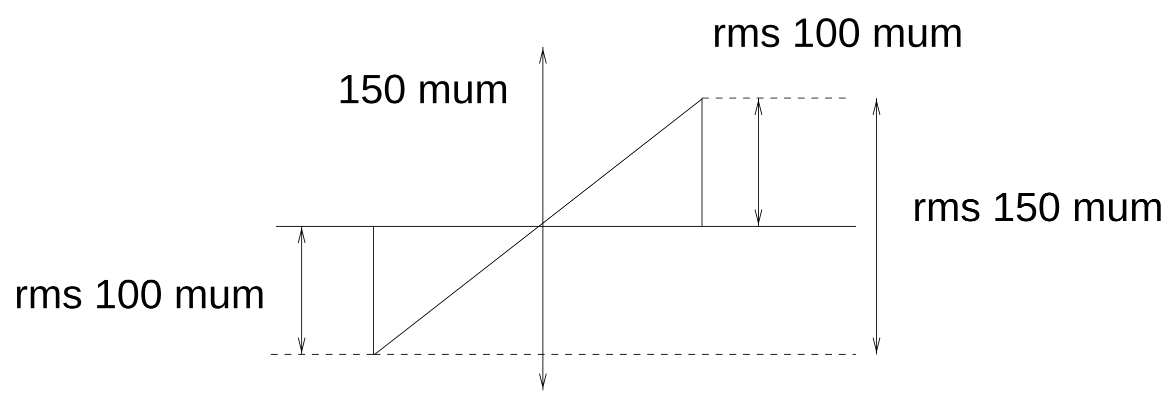
/Text/LHC/2001/coll/7nov01

Survey - meeting J.P.Quesnel,C.Fischer and JBJ

- rms survey default
  $t = 0 : \sigma = 150$ m, truncated at 2σ
  $t = 1$ yr : $\sigma = 200$ m, truncated at 2σ ?
- This relatively to a ref.line drawn between quads
- This also for standard ajustment tools (which can react,...)
- Tunel movements shall not induce significant angular misalignment
- IR3 and IR7 both very quiet (less movement than average)

Collimators

- If the mechanics allows soft adjustments, we can hope for better values



- JPQ commented on radiation levels: mounting tables for alignment in the lab and adequate structure in the tunnel required to allow straight interchange

  impact on mechanical design

Collimators and collective effects

Preliminary discussion : D. Brandt, L. Vos and BJ

- a tapering is needed because of longitunal instabilities related to the rather weak RF voltage in LHC - 91-100mm at each end (for tank inner height 50mm)
- $\Rightarrow$ consequence for layout (bj, to be reviewed when more other studies done
- unless the distance between the jaw and the wall of the tank is very small (what is ’small’, to be discussed. Gerard to make an offer?), a RF contact will be needed all along the jaw).
- Daniel an Luc also noticed the presence of a vacuum port at each end of a collimator. To be reevaluated - vac. port on the tank?
- Luc suggested getter coating to simplify vacuum
- Further iteration needed with more people

Thermal Studies

Preliminary discussion : Tadeusz Kurtyka, R. Valbuena and BJ

- They would much prefer the thermal calculations to be under their control, with input from us (CERN+IHEP)
- No staff inside CERN
- But good and inexpensive collaboration with Cracow and ENS-Cachan
- Time-scale (their views):
  - Collimator construction $\sim$ 2 years
  - $\Rightarrow$ No need to do thermal studies+design as early as next June
  - Agreed/proposed for a further meeting with BI on this