Status of the thin lens PS model and of the loss studies in the PS

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Goal

- Numerical tools have been developed for the design and optimization of the LHC collimation system through the production of detailed loss maps (PhD Thesis of G. Robert-Demolaize).
- These tools were adapted to the PS machine by using the detailed aperture model (O. Berrig) and a thin lens version for tracking with SIXTRACK.
- Serious debugging is necessary in order to understand the implications of adapting the tools to low energy rings.
- A benchmarking campaign was initiated in order to reproduce the loss patterns simulated and observed in the PS complex (see APC talks by S. Gilardoni).
- The ultimate goal is to have robust tools for beam loss studies in low energy synchrotrons and use them for the design of the collimation system in the new PS2 machine.

Tracking with SixTrack (I)

- SixTrack is a single particle tracking code which in its primary version allows to track a maximum of 32 particle couples (64 particles).
- CollTrack, a new module developed for collimation studies, increases considerably the number of particles (~10^6 particles) and gives the possibility to track an external distribution ($2x10^3$ particles) over hundreds of turns.
- Possibility to insert collimators and use particle scattering codes (like K2).
- Interaction with machine aperture model. The loss location of the particles tracked is given with an accuracy of 10cm.
- Among other input files, it is necessary to provide a thin lens model of the lattice, through the **MAKETHIN** command in MAD-X.
- Some problems were encountered while trying to do the conversion.

Thin Lens Model (I)

- In MAD-X the combined function magnets are modeled as sector bends **(SBEND),** with a quadrupole component and pole face angles describing the edge focusing.
- MAKETHIN ignores completely the effect of the fringe fields (edge focusing and higher order effects).
- The DIPEDGE element in MAD-X can solve the problem of the edge focusing when passing to thin lenses, by adding it on either side of an SBEND (with a zero pole face angle).

label : DIPEDGE, h=real, e1=real, fint=real, hgap=real, tilt=real;

- Some misunderstanding in the MADX manual regarding the parameters of this element, namely **h** is not the curvature of the pole face but the curvature of the reference orbit within the dipole.
- **DIPEDGE** is limited to only linear terms…

Edge Focusing in MAD-X

- Transfer maps for dipoles in MAD are composed of three maps, fringe field at entrance $F^{(1)}$, body of the dipole B and fringe field at the exit $F^{(2)}$, using TRANSPORT formalism

$$\mathbf{F = F^{(1)} * B * F^{(2)}}$$

- Working only with the fringe fields.

Non-linear term coming from the gradient of the quadrupole

Term due to the pole face angle itself

Term due to the curvature of the pole face,

$$F^{(i)} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ +h\tan\psi_i & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -h\tan\overline{\psi_i} & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}.$$

$$\begin{aligned} f_3^{(1)} = & \frac{1}{6}\left(\frac{h}{R_1}\sec^3\psi_1 + 2K_1\tan\psi_1 - 2h^2\tan^3\psi_1\right)x^3 \\ - & \frac{1}{2}\left(\frac{h}{R_1}\sec^3\psi_1 + 2K_1\tan\psi_1 - h^2\tan\psi_1(\sec^2\psi_1 - \tan^2\overline{\psi_1})\right)xy^2 \\ + & \frac{h}{2}\tan\psi_1\left(x^2p_x\tan\psi_1 - 2xyp_y\tan\overline{\psi_1}\right) - \frac{h}{2}p_xy^2\sec^2\psi_1. \end{aligned}$$

Linear terms due to the pole face angle

Term due to the longitudinal dependence of the field

$$\overline{\psi_i} = \psi_i - hgI_1(1 + \sin^2\psi_i).$$

Thin Lens Model (II)

- Notice that the effect of both, linear and non-linear terms, is greater in small machines (small ρ, h=1/ρ).
- If pole face angles are zero, just terms containing only the secant remain.
- DIPEDGE only includes edge focusing term

	Thick element with pole face angles	**Dipedge**	
Qx	6.2714	6.3329	**0.98%**
Qy	6.2860	6.2423	**-0.70%**
Qx'	10.3748	69.0589	**565.64%**
Qy'	4.684	-27.4726	**-686.52%**

- MADX simulation for CT extraction.
- Note that the difference in tunes comes from not including the non-linear component of the fringe-field (sextupole-like) and having the extraction bumps on (quadrupole feed-down).

Thin Lens Model (III)

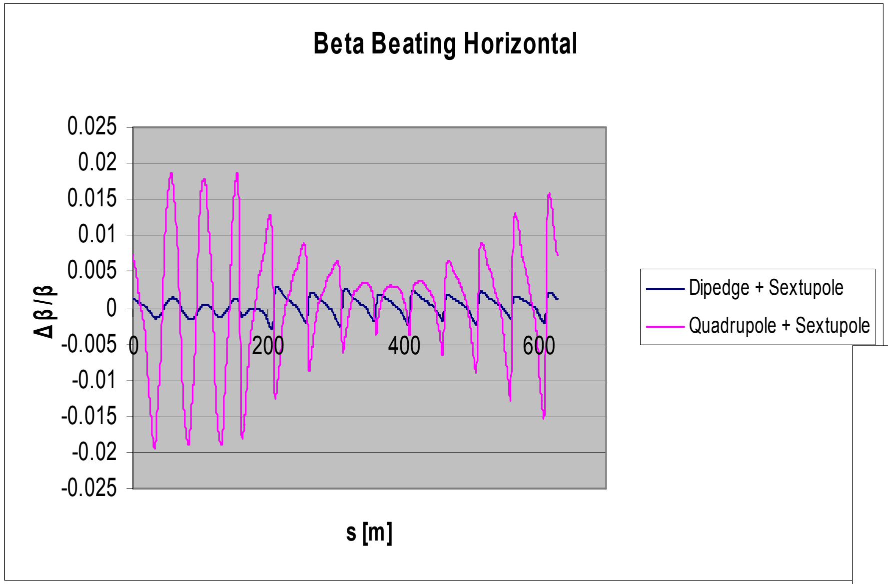
- In order to have the correct chromaticity it is necessary to add the sextupole-like terms. Including the term coming from the gradient and the pole face angle of the magnet is straightforward, but the one due to the longitudinal dependence of the field (depending on positions and **momenta**) is not

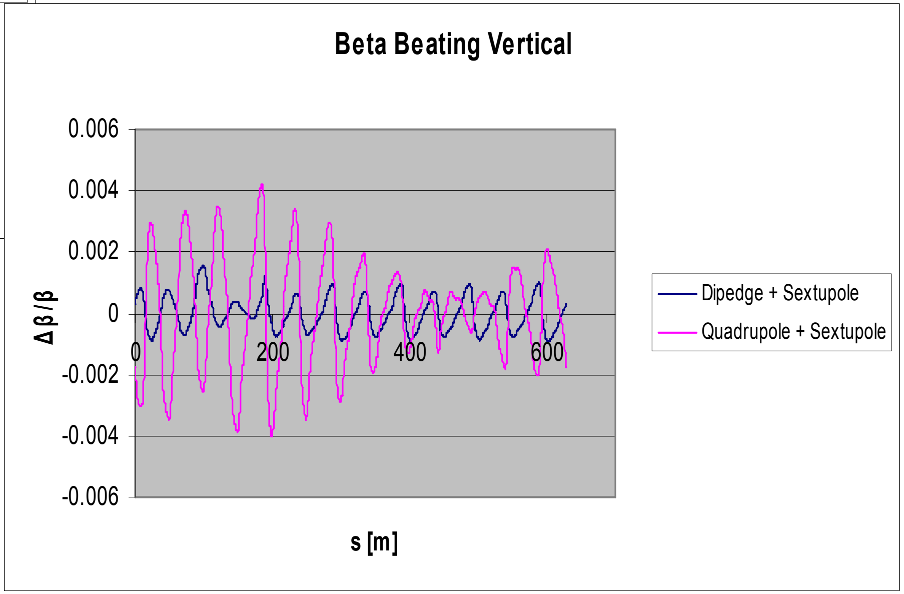
	Pole Face Angle	**Dipedge + Sextupole**	**Quadrupole + Sextupole**	
Qx	6.2714	6.2719	6.2755	
Qy	6.2860	6.2855	6.2868	
Qx'	10.3748	10.8297	10.8264	**4.35%**
Qy'	4.6840	4.4085	4.3928	**-6.22%**

- Now the values are quite similar to the initial ones. The difference in the chromaticity comes from the terms depending on positions and momenta, which are not included.
- In the last column the **DIPEDGE** element has been replaced by a thin-lens quadrupole.

Thin Lens Model (IV)

- Dipedge presents smaller beta-beating (especially horizontal), with respect to thin quadrupole





Thin Lens Model (V)

- Finally, we observed some discrepancies in the chromaticity in the thin lens model (mainly in the horizontal plane). The reason is that the sector bends are split in multipoles, and the fringe fields are not considered, not even those terms which are always non-zero, even for zero pole phase angle

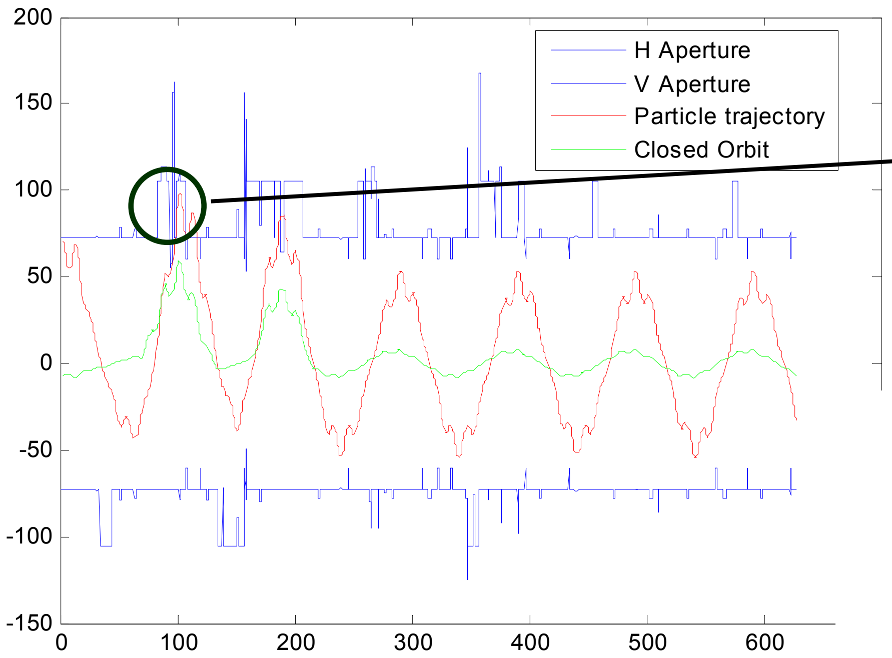
	Thick lens model. Pole Face Angle	Thin lens model. Dipedge + Sextupole	
Qx	6.2714	6.2697	**-0.03%**
Qy	6.2860	6.2852	**-0.01%**
DQx	10.3748	8.6010	**-17.10%**
DQy	4.684	3.9875	**-14.87%**

- Correct treatment can be only done using PTC for tracking
- A preliminary “poor-man” approach would be to match the chromaticities of the thin lens model to the thick lens model values

Tracking with SixTrack (II)

- Once solved the problems with the thin lens model, the next step is to track the particle distribution scattered from septum 31 during the CT extraction (see S. Gilardoni APC presentations). Two important points to highlight:
  - Some problems encountered due to the change of linux and compiler versions
  - Some misprints in Colltrack manual created also some confusion regarding the input tracking coordinates.The manual will be updated by G. Robert-Demolaize as soon as possible.
- Now we are ready to track the particles and get the loss position with a precision of 10 cm.

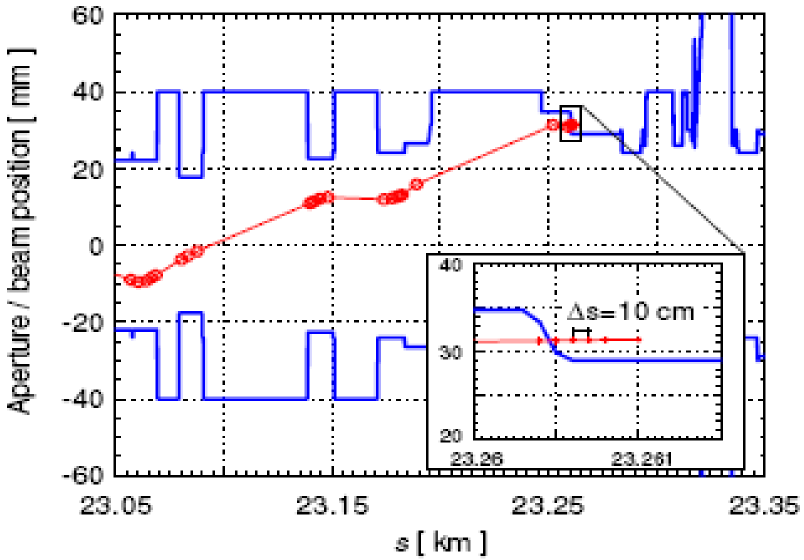
Tracking with SixTrack (III)



Output from SixTrack

S=107.46
X=0.734E+2
X'=-0.106E+1
Y=0.0E+0
Y'=0.0E+0

Up to $20*10^3$ can be tracked from an given external distribution, over hundred turns.



10 cm accuracy in loss location.
From G. Robert-Demolaize

Conclusions

- SixTrack almost **fulfills** the needs for tracking particles in a low energy ring like PS.
- Simulations will be carried out in order to simulate and reproduce the loss patterns simulated and observed in the PS complex (see APC talks by S. Gilardoni).
- The possibility of tracking **thousands of particles** over **hundreds turns** will increase the statistics available and will allow to include multi-passage effects.