Simulations for FCC-ee beam self-polarization

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Goal since October Workshop: a complete simulation of the effect of misalignements.

Optics: 45 GeV optics with smaller $\boldsymbol{\beta_y^*}$ from September 2017

- 60 deg FODO.
- $\hat{\boldsymbol{\beta}}_{\boldsymbol{y}}$ is smaller but focusing is stronger too.
- As a consequence, the SY sextupoles became stronger and life did not become easier.

Reminder from December 14 meeting: two (more) problems encountered i.e.

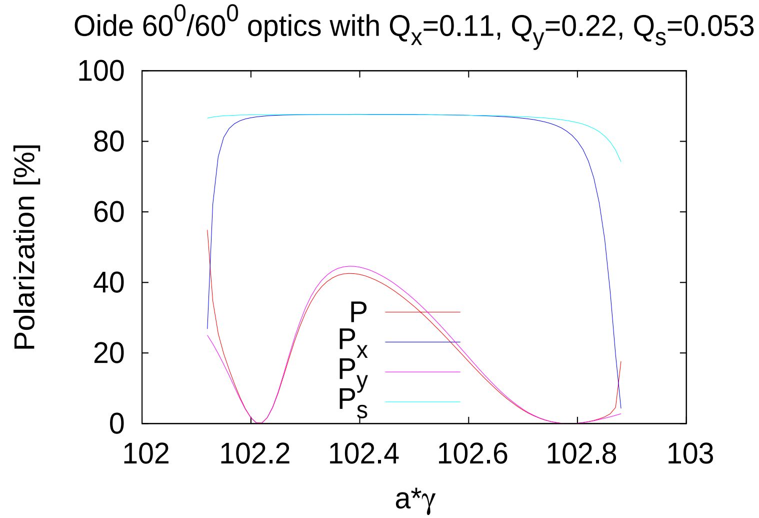
- Small $\boldsymbol{\epsilon_y}$ and $\boldsymbol{D^y_{rms}}$ is no warranty for high (linear?) polarization
- Problems by tracking with SITROS (and MAD-X PTC) (particles losses) even reducing alignment errors, skipping errors on IR quads and BPM.
  $\rightsquigarrow$ back to 90/90 optics.

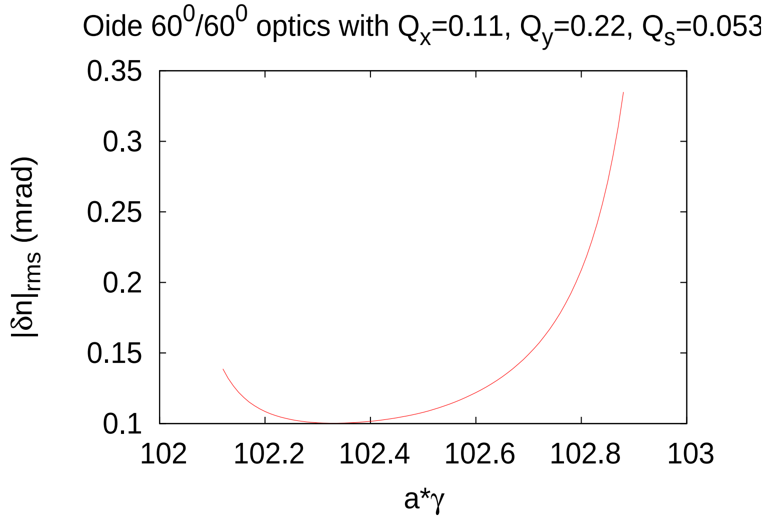
In the meantime....

- After switching to the January optics version, the tracking problem disappeared!
- Therefore I am skipping almost all results obtained between December and now using the October version.

Some optics show a small $\boldsymbol{P_y}$ although $\boldsymbol{\epsilon_y}$ and $\boldsymbol{D_y}$ are small.

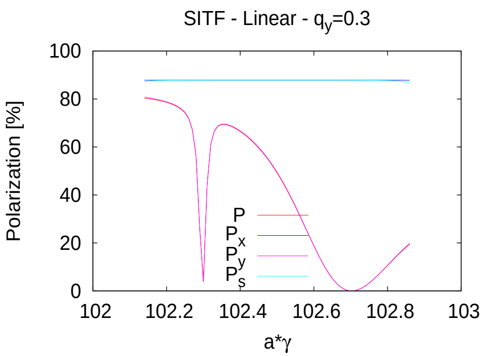
An example (October 2017 60/60 deg optics):

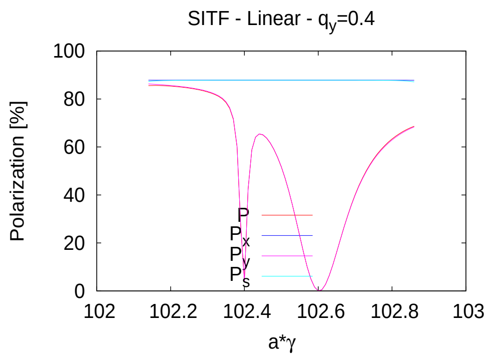


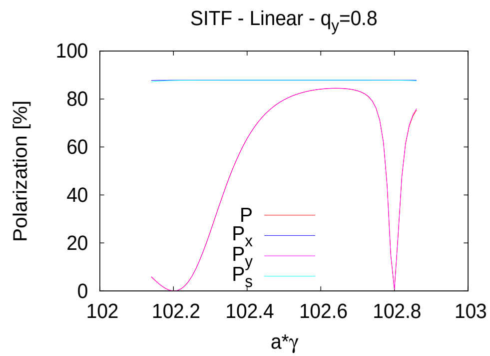


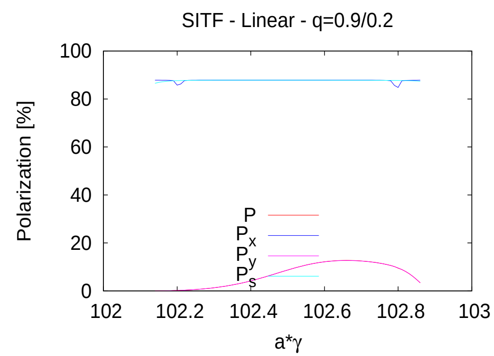
Tune scan

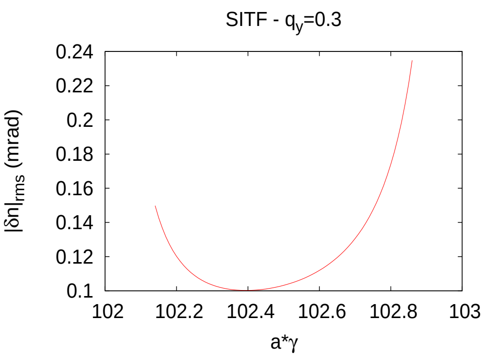
⇓

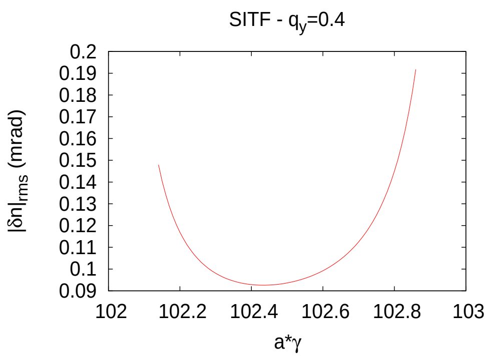


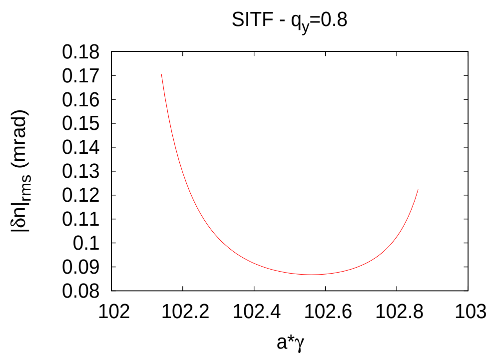


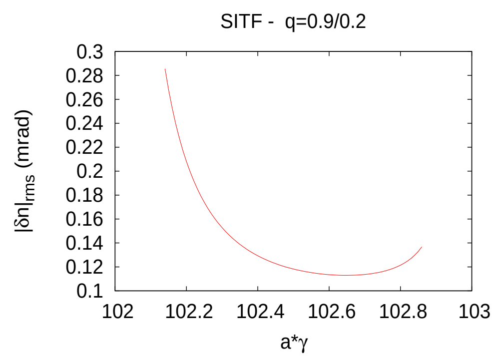












Why is 0.1/0.8 better then 0.1/0.2 ?

Linear approximation for spin diffusion:

$$\frac{\partial \hat{n}}{\partial \delta}(\vec{u}; s) = \vec{d}(s) = \frac{1}{2}\Im\Big\{(\hat{m}_0 + i\hat{l}_0)^* \sum_{k=\pm x,\pm y,\pm s} \Delta_k\Big\}$$

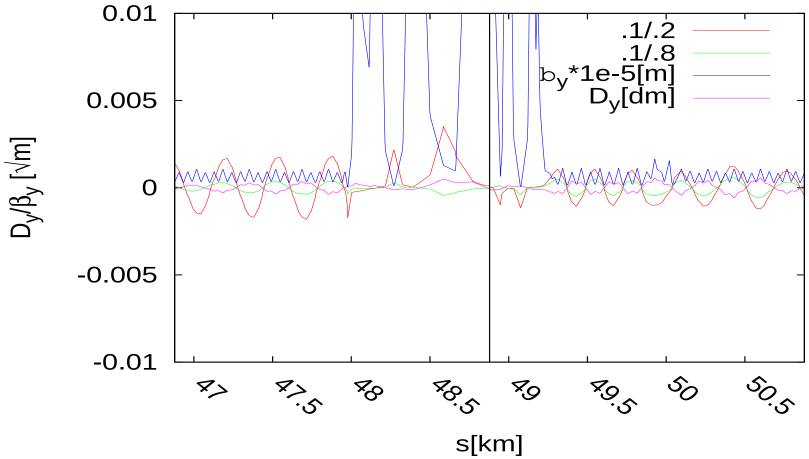
$$\Delta_{\pm x,\pm y} = (1 + a\gamma)\frac{e^{\mp i\mu_{x,y}}}{e^{2i\pi(\nu\pm Q_{x,y})} - 1}\frac{[-D \pm i(\alpha D + \beta D')]_{x,y}}{\sqrt{\beta_{x,y}}}\; J_{x,y}$$

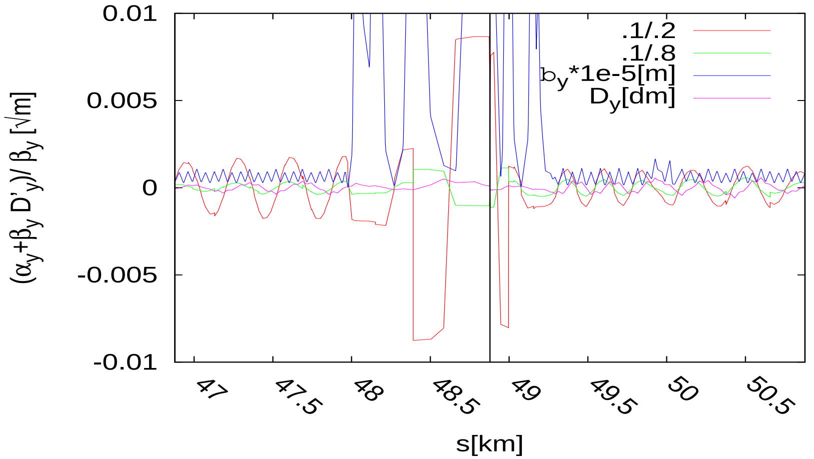
$$\Delta_{\pm s} = (1 + a\gamma)\frac{e^{\pm i\mu_s}}{e^{2i\pi(\nu\pm Q_s)} - 1}\; J_s$$

$$J_{\pm x,\pm y} = \int_s^{s+L} ds'(\hat{m}_0 + i\hat{l}_0)\cdot\left\{\begin{array}{c}\hat{y}\sqrt{\beta_x}\\ \hat{x}\sqrt{\beta_y}\end{array}\right\} K e^{\pm i\mu_{x,y}}$$

$$J_s = \int_s^{s+L} ds'(\hat{m}_0 + i\hat{l}_0)\cdot(\hat{y}D_x + \hat{x}D_y)\, K$$

Plotting the factor $\frac{[-D_y \pm i(\alpha_y D_y + \beta D'_y)]}{\sqrt{\beta_y}}$ which multiplies $J_{\pm y}$:

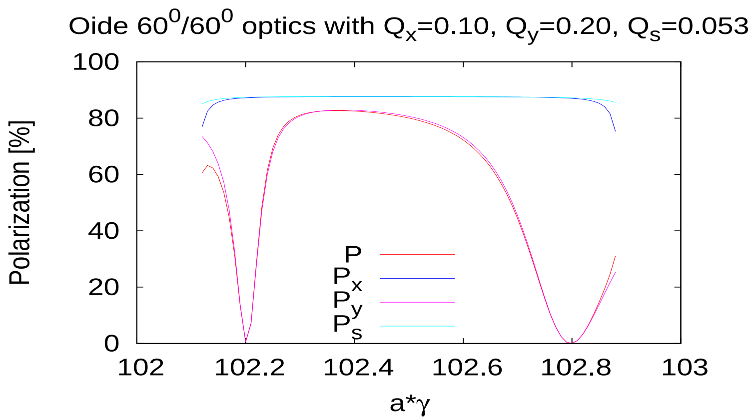


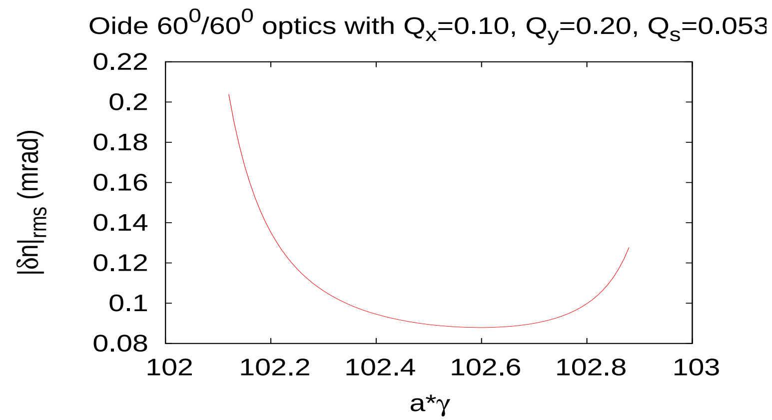


The factor is much smaller when the tunes are moved to .1/.8

$\rightsquigarrow$ Instead of correcting linear coupling and spurious vertical dispersion, we should try minimizing $[-D_y \pm i(\alpha_y D_y + \beta D'_y)]/\beta_y$.

Found skew quadrupole settings improving $\boldsymbol{\Delta_{\pm y}}$ at expenses of betatron coupling with .1/.2 tunes:





	$\boldsymbol{x_{rms}}$ ($\boldsymbol{\mu}$m)	$\boldsymbol{y_{rms}}$ ($\boldsymbol{\mu}$m)	$\boldsymbol{D^y_{rms}}$ (mm)	$\boldsymbol{\epsilon_x}$ (nm)	$\boldsymbol{\epsilon_y}$ (pm)	$\boldsymbol{\lvert C^-\rvert}$
no skews	41	16	12	0.222	12	0.017
with	40	17	7	0.220	5	0.022

But...problems with SITROS tracking: no equilibrium found, many particles “lost”!

********* Start excursus on tracking *********

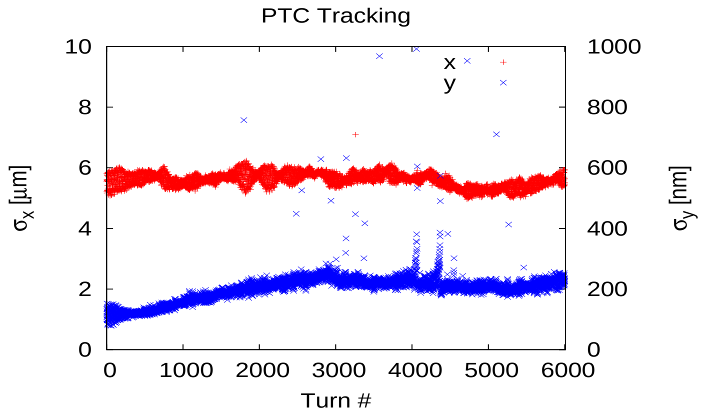
Tracking problems - Comparison with MAD-X PTC

October 60/60 deg optics.

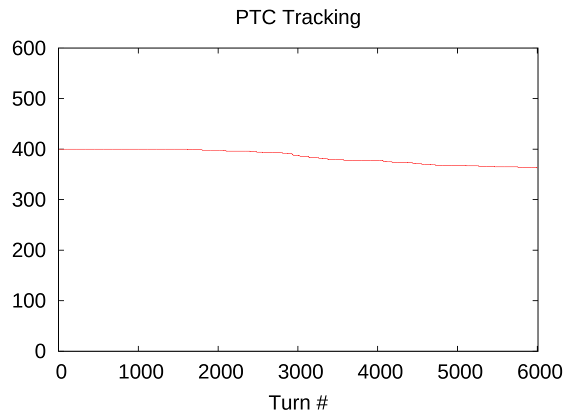
Very last suggestions from Tobias (February 20, 2018)

```
ptc_create_universe;
PTC_CREATE_LAYOUT, MODEL=2, NST=1, METHOD=4, exact=true, resplit, thin=0.001, xbend=0.001;
ptc_align;
PTC_SETSWITCH, debuglevel=1,maxacceleration=false,exact_mis=true,time=true,
  totalpath=false,fringe=true,radiation=true,stochastic=true,envelope=true;
PTC_TWISS, ICASE=6, CLOSED_ORBIT, NO=2, RMATRIX;
ptc_start, x=-.765E-05, y= -.138E-07, px=0.359E-05, py= -.335E-04;
!call, file="my_ptcstart_gauss.dat";
PTC_TRACK, ICASE=6, CLOSED_ORBIT, RADIATION,dump, turns=1000, ffile=1;
PTC_TRACK_END;
stop;
```

Results for the machine with errors and 8 wigglers

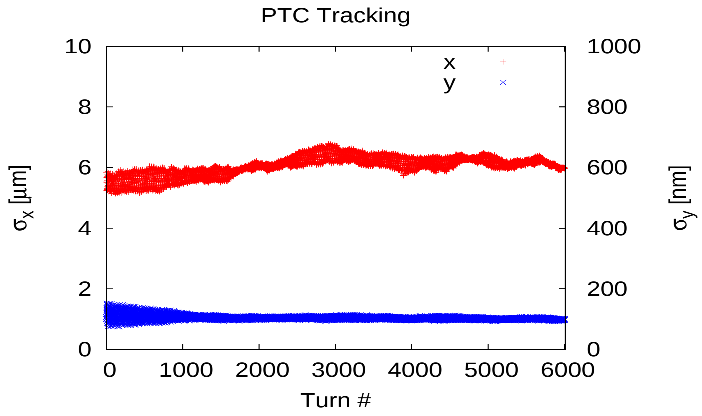


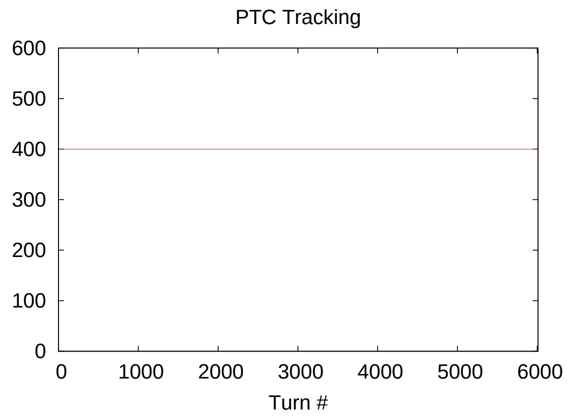
	$\boldsymbol{\sigma_x}$	$\boldsymbol{\sigma_y}$
	($\boldsymbol{\mu}$m)	(nm)
analytical	5.8	78
PTC Tracking	$\simeq$ 5.6	$\simeq$ 230



$\rightsquigarrow$ PTC tracking confirms a disease in the vertical plane, not as serious as SITROS tracking?

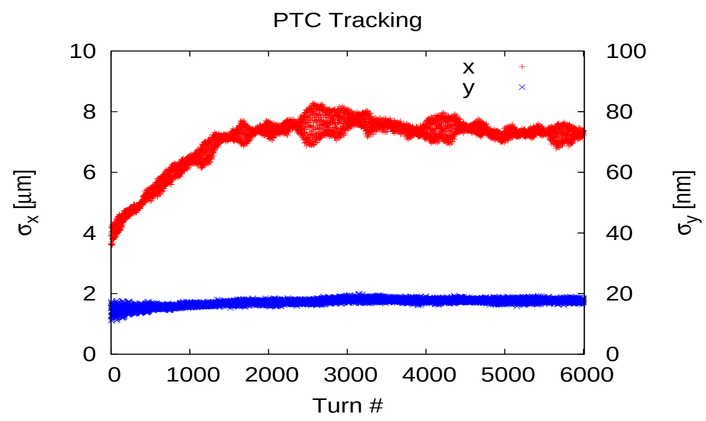
Repeat tracking for the perturbed machine after turning wigglers off

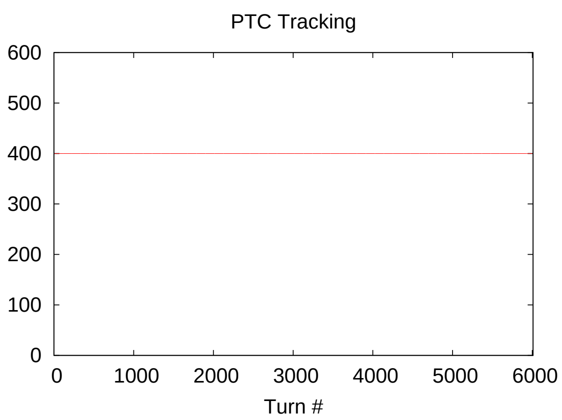




	$\boldsymbol{\sigma_x}$ ($\boldsymbol{\mu}$m)	$\boldsymbol{\sigma_y}$ (nm)
analytical	6.3	69.5
PTC Tracking	$\simeq 6$	$\simeq 97$

Repeat tracking for the perturbed 90/90 optics with wigglers on ($\tau_{10\%}$= 2.8 h)





	σ_x	σ_y
	(μm)	(nm)
analytical	7.8	18.9
PTC Tracking	$\simeq$ 7.3	$\simeq$ 18

********* End excursus on tracking *********

In the past I used $\boldsymbol{\delta_Q^y}$=200 $\boldsymbol{\mu}$m. After introducing quads horizontal misalignments and roll angles as well as BPM errors, misalignments had to be decreased to get a stable optics.

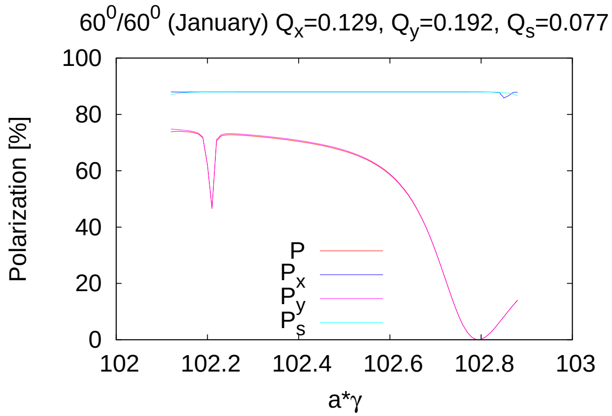
Set of errors assumed (but very limited statistics!)

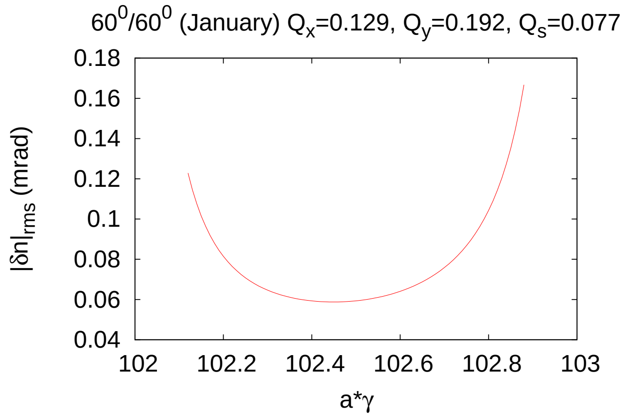
	IR Quads	IR BPMs	other Quads	other BPMs
$\boldsymbol{\delta x}$ ($\boldsymbol{\mu}$m)	10	10	30	30
$\boldsymbol{\delta y}$ ($\boldsymbol{\mu}$m)	10	10	30	30
$\boldsymbol{\delta \theta}$ ($\boldsymbol{\mu}$rad)	10	10	30	30
calibration	-	1%	-	1%

New January 45 GeV optics, 8 wigglers, $\tau_{10\%}$=2.7 h with B^+=0.568 T.

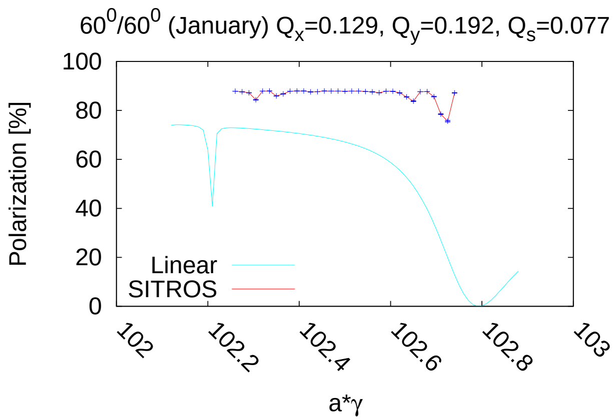
One error realization.

	x_{rms} (μm)	y_{rms} (μm)	D^y_{rms} (mm)	ϵ_x (nm)	ϵ_y (pm)	$\vert C^-\vert$
no skews	26	13	2	0.215	0.5	0.0014



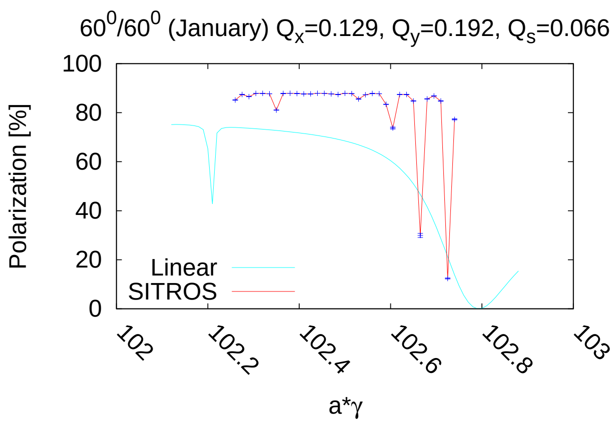


P_y limiting polarization, but P_{lin} large enough.



V=840 MV

	σ_x (μm)	σ_y (nm)	σ_ℓ (mm)
analytical	5.714	23.0	3.356
SITROS Tracking	8.526	23.8	3.439

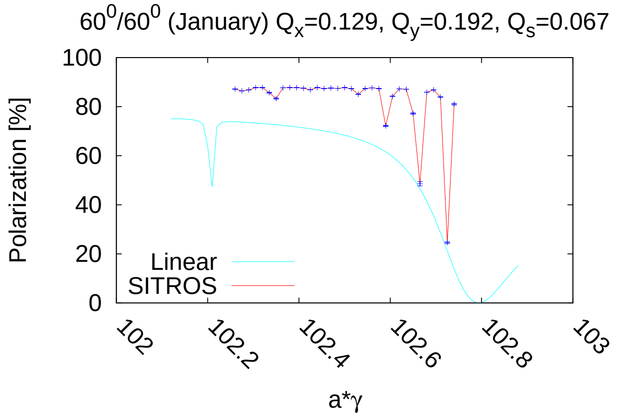


V=620 MV

	σ_x (μm)	σ_y (nm)	σ_ℓ (mm)
analytical	5.716	23.9	3.909
SITROS Tracking	8.629	43.6	3.890

Tracking shows larger polarization...

The wiggler field may be increased to $\boldsymbol{B}^{+}= 0.664$ T to obtain $\boldsymbol{\tau_{10\%}}$=1.7 h



V=700 MV

	$\boldsymbol{\sigma_x}$	$\boldsymbol{\sigma_y}$	$\boldsymbol{\sigma_\ell}$
	($\boldsymbol{\mu}$m)	(nm)	(mm)
analytical	5.803	27.4	4.398
SITROS Tracking	9.602	38	4.461

Polarization – 80 GeV

New January 80 GeV optics, no wigglers.

Tunes in presence of synchrotron radiation for the unperturbed machine:

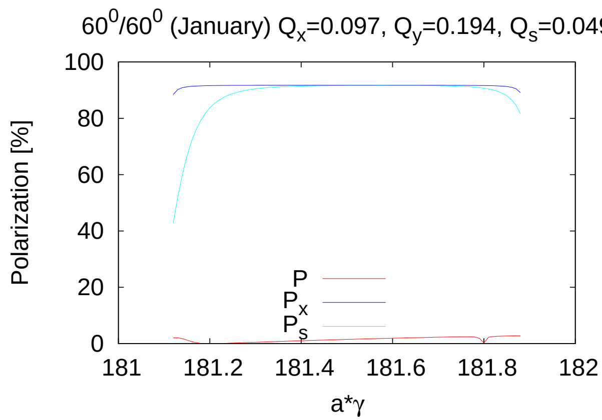
	MADX	SITF	MADX	SITF	MADX	SITF
	S.R. off		S.R. on		S.R. on & SEXTS off	
Q_x	269.100	.100	269.138	.138	269.100	.101
Q_y	269.200	.200	269.128	.129	269.200	.196

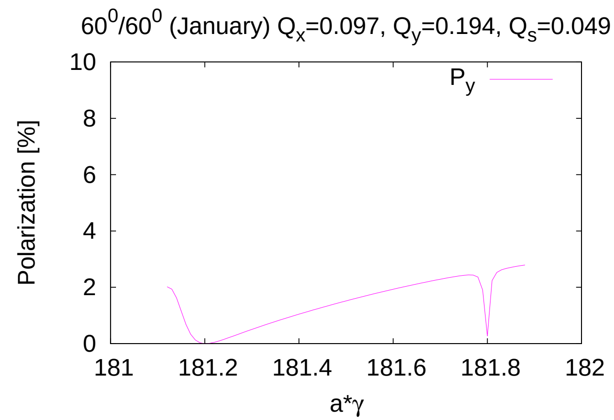
Large feed-down effect of sextupoles!

One error realization:

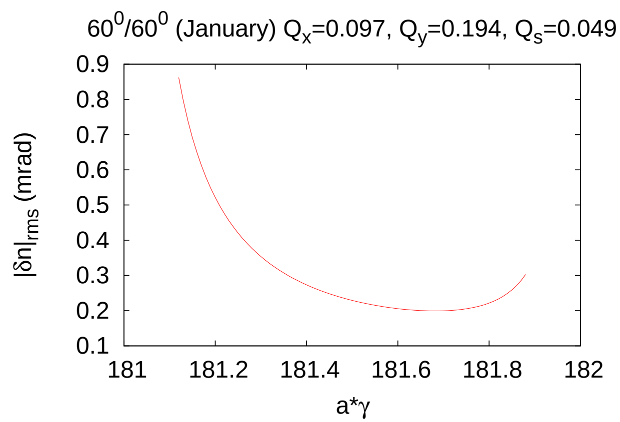
	x_{rms} (μm)	y_{rms} (μm)	D^y_{rms} (mm)	ϵ_x (nm)	ϵ_y (pm)	$\lvert C^-\rvert$
no skews	144	11	2	0.792	0.1	< 0.001

Tunes adjusted taking into account sextupole effect.



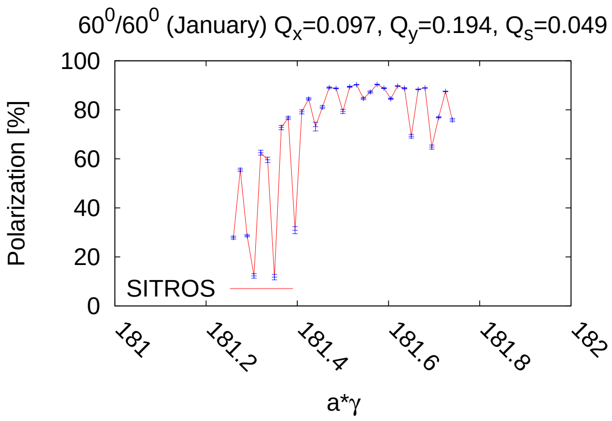


$\Leftarrow$?



- Is it there again a problem with $\frac{[-D_y \pm i(\alpha_y D_y + \beta D'_y)]}{\sqrt{\beta_y}}$?
- Is P_{lin} relevant?

Try SITROS...

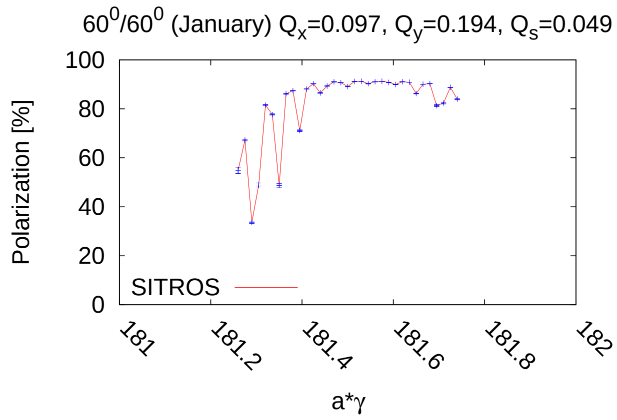


V= 700 MV

	$\boldsymbol{\sigma_x}$ ($\boldsymbol{\mu}$m)	$\boldsymbol{\sigma_y}$ (nm)	$\boldsymbol{\sigma_\ell}$ (mm)
analytical	13.22	19.5	3.079
SITROS Tracking	12.66	44.1	3.105

Correctors added after each bending magnet for correcting sawtooth effect: linear polarization shows no improvement!

Tracking shows some improvement.



V= 700 MV

	σ_x (μm)	σ_y (nm)	σ_ℓ (mm)
analytical	12.595	19.1	3.083
SITROS Tracking	12.206	26.3	3.108