Slow Extraction Workshop 2017
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From high accuracy particle tracking to slow extraction simulations

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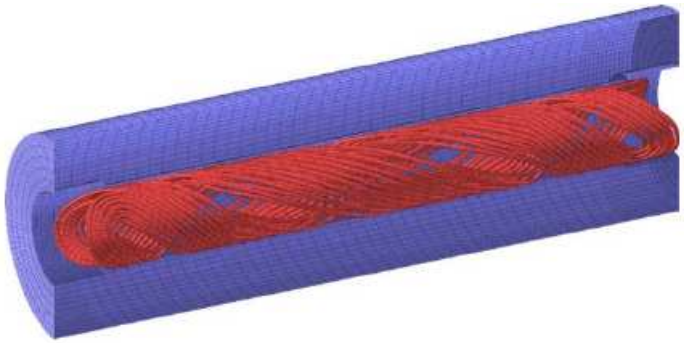
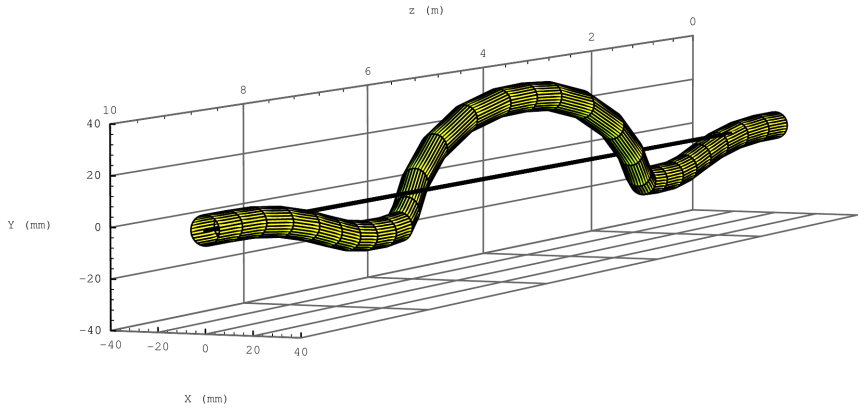
Contents

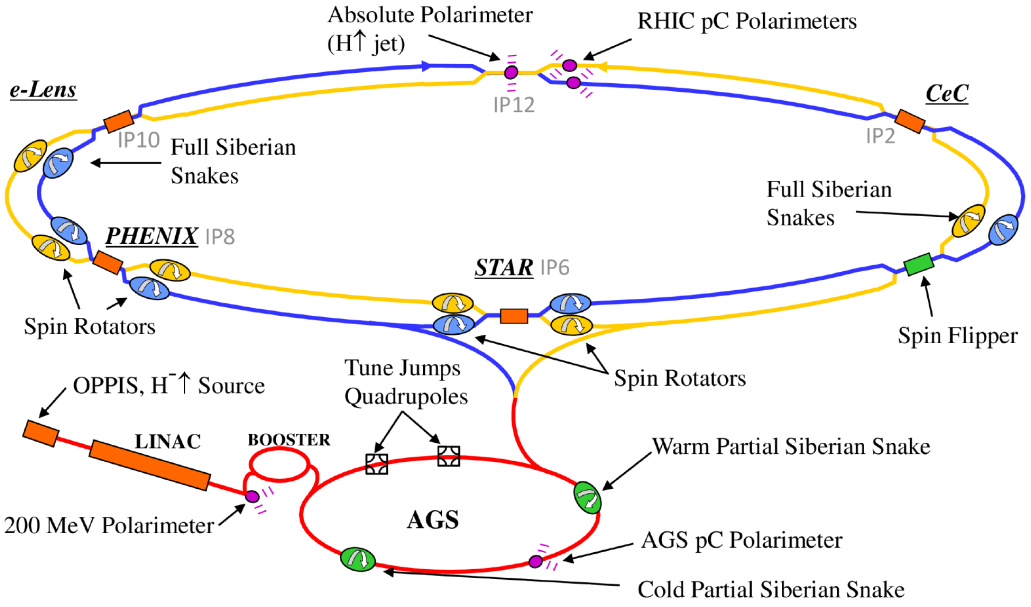
1 STEPWISE RAY-TRACING, WHAT IT MEANS

- **At RHIC we have snakes, everywhere. Siberian snakes, some cold some warm.**
- **Mastering polarization requires very accurate knowledge of orbits & focusing.**

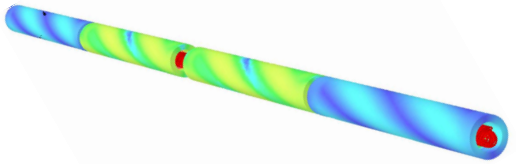
OPERA model of the AGS cold snake :
A twisted dipole coil with variable pitch
+ superimposed solenoid coil (not shown) for coupling compensation

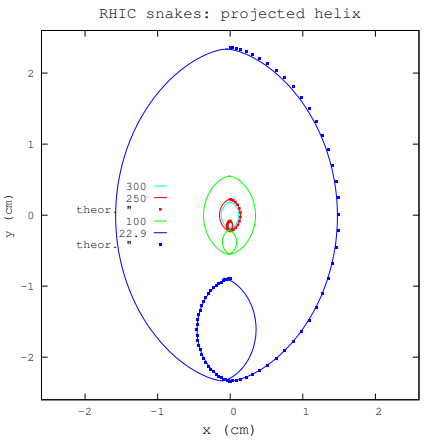






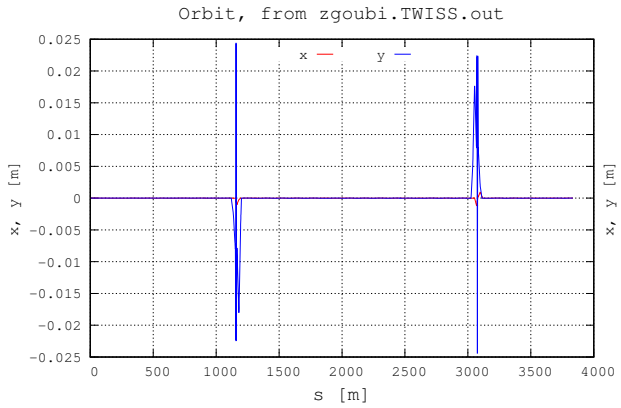
Orbits in 4-helix RHIC module:



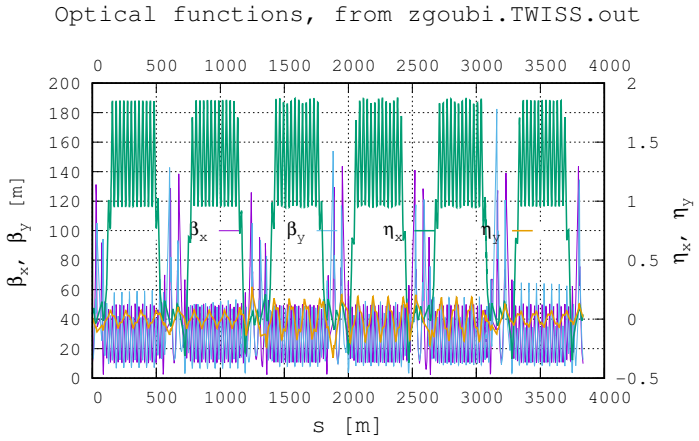


RHIC OPTICS, WITH SNAKES

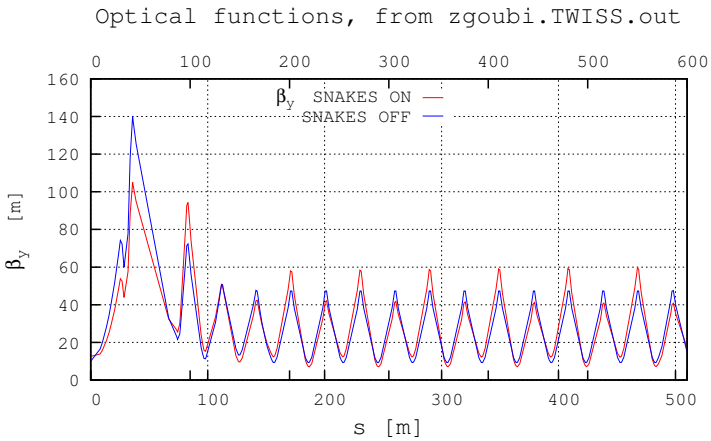
- ◇ we use their 3D OPERA field maps
- ◇ all other magnets : theoretical $\vec{B}(x, y, z)$
- ◇ # of steps $= \mathcal{L}/$step size
- $\approx (3800\text{m}/2)/0.01\text{m} = 380,000[/\text{turn}]$
- ◇ *Note : CPU time is* 0.5 *sec/turn* $\Rightarrow$
- 10^5 *snake resonance crossing takes* $13hrs$
- ◇ Optical functions (like here) :
- derived from coordinates



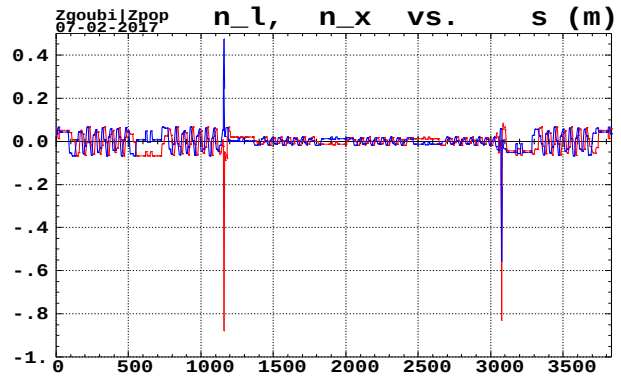
Snake induced orbit.



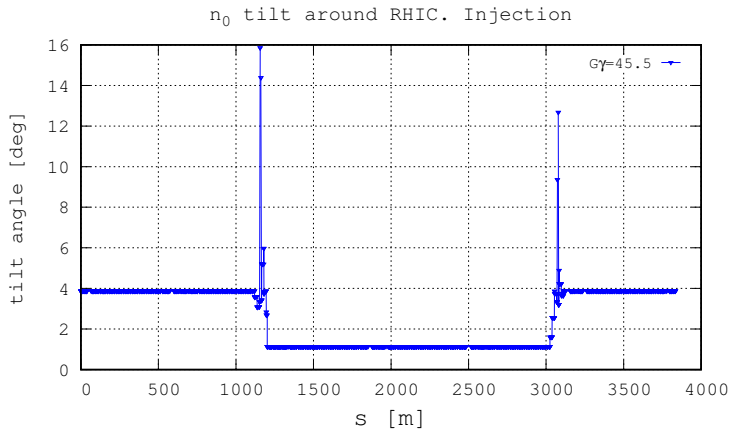
At injection snakes cause $\Delta Q_y = 0.063$**.**



IP6-Arc–IP8 region in RHIC.

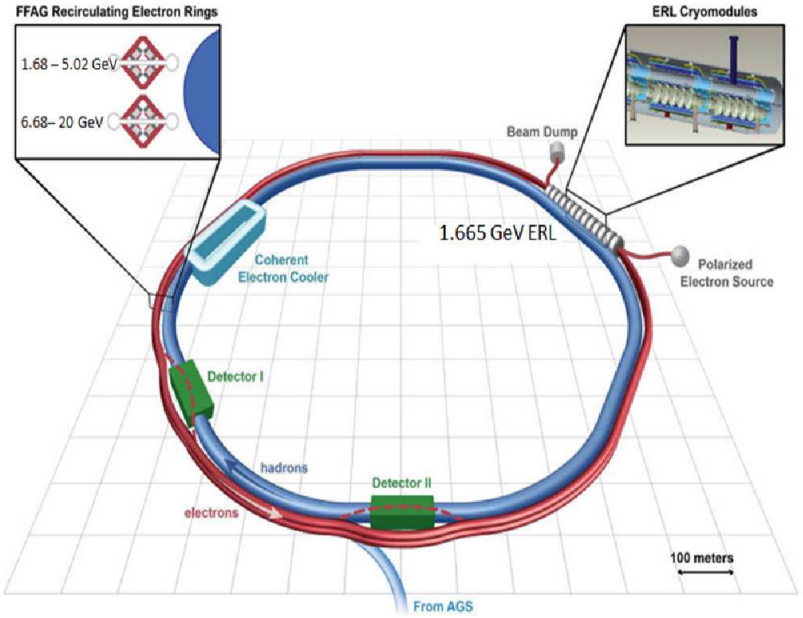


n_l **(red),** n_x **(blue) components of** $\vec{n}_0$**.**

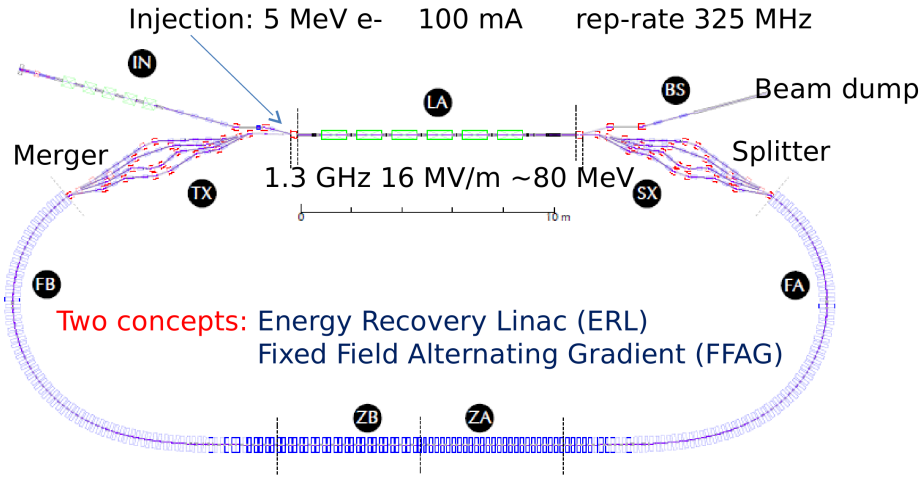


Vertical tilt of $\vec{n}_0$ **around RHIC.**

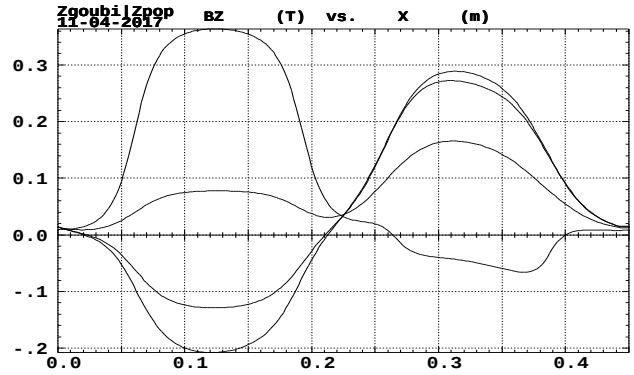
- **Simulation of Cornell's CBETA: a linear FFAG lattice, many recirculations in a single pipe**

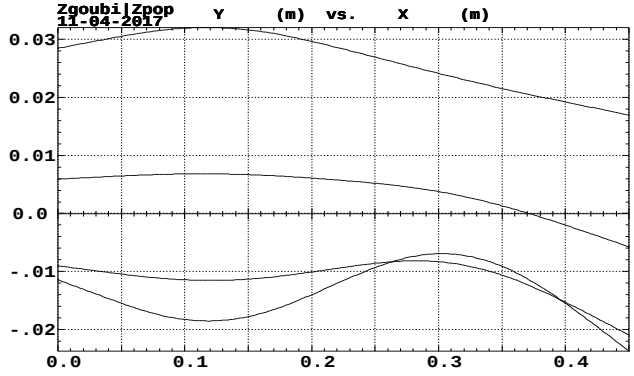


Cβ : a prototype electron accelerator for the eRHIC project

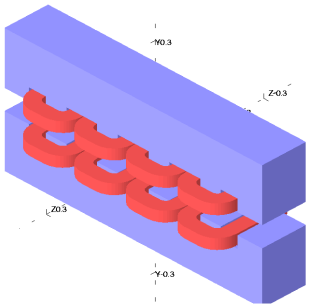


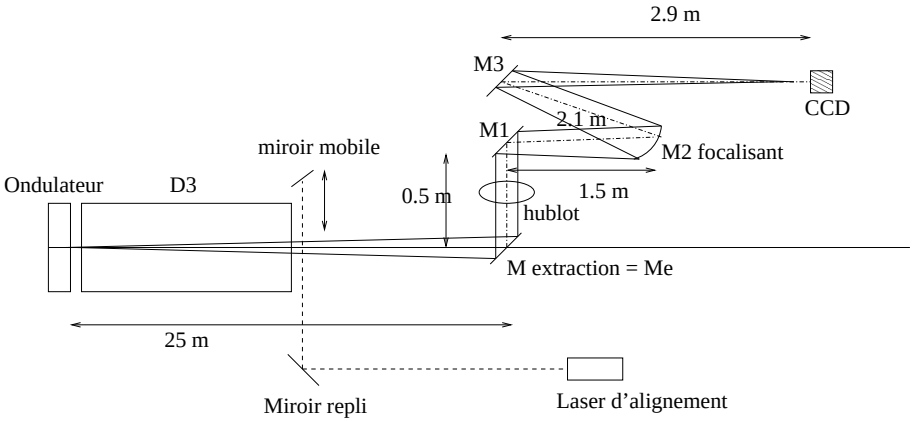
Two concepts: Energy Recovery Linac (ERL)
Fixed Field Alternating Gradient (FFAG)





• The SR beam diagnostics installations at LHC





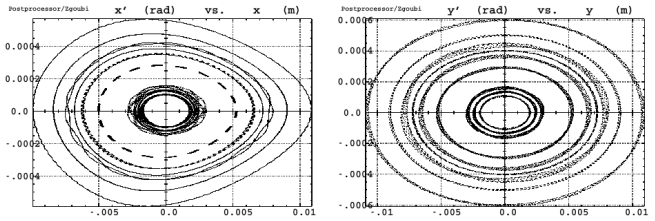


Figure 6: Initial amplitudes of 20, 25 and 30σ, three initial angles 15° 45° and 75° in the {x,y} plane, 5 10^4 turns. Fringe fields set in all dipoles and quadrupoles, chromaticity sextupoles on, no undulator.

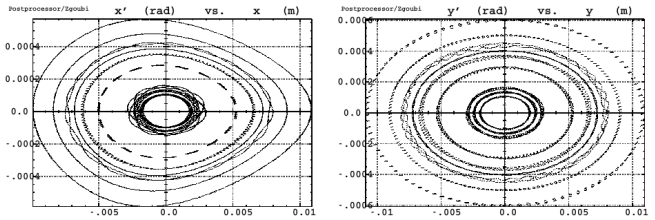
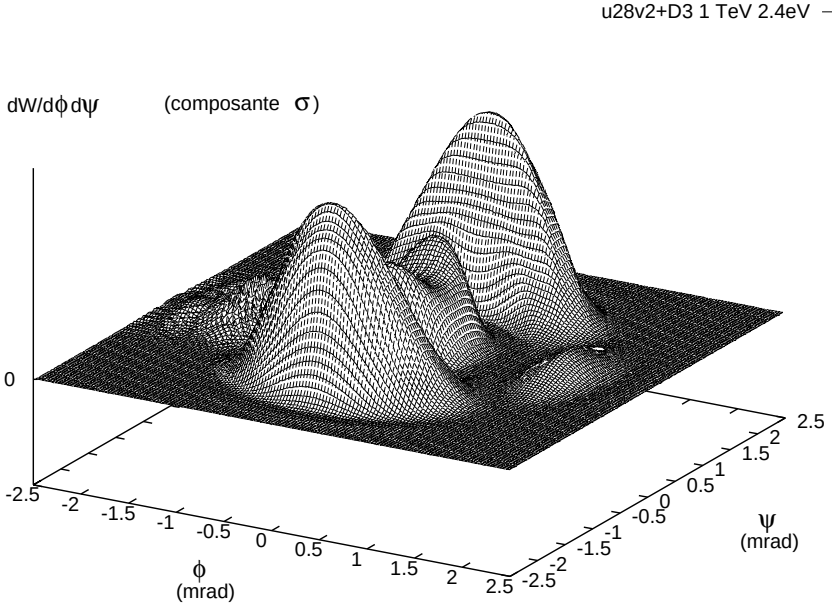
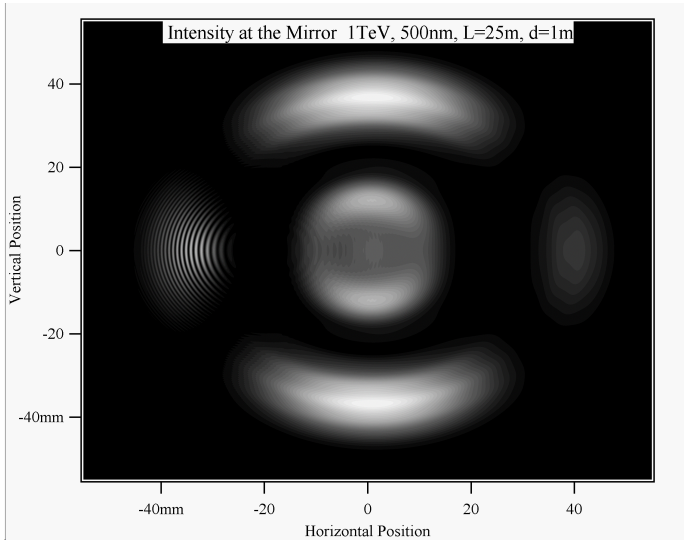


Figure 7: Initial amplitudes of 20, 25 and 30σ, , three initial angles 15° 45° and 75° in the {x,y} plane, 5 10^4 turns. Fringe fields set in all dipoles and quadrupoles, chromaticity sextupoles on, undulator excited at full field.

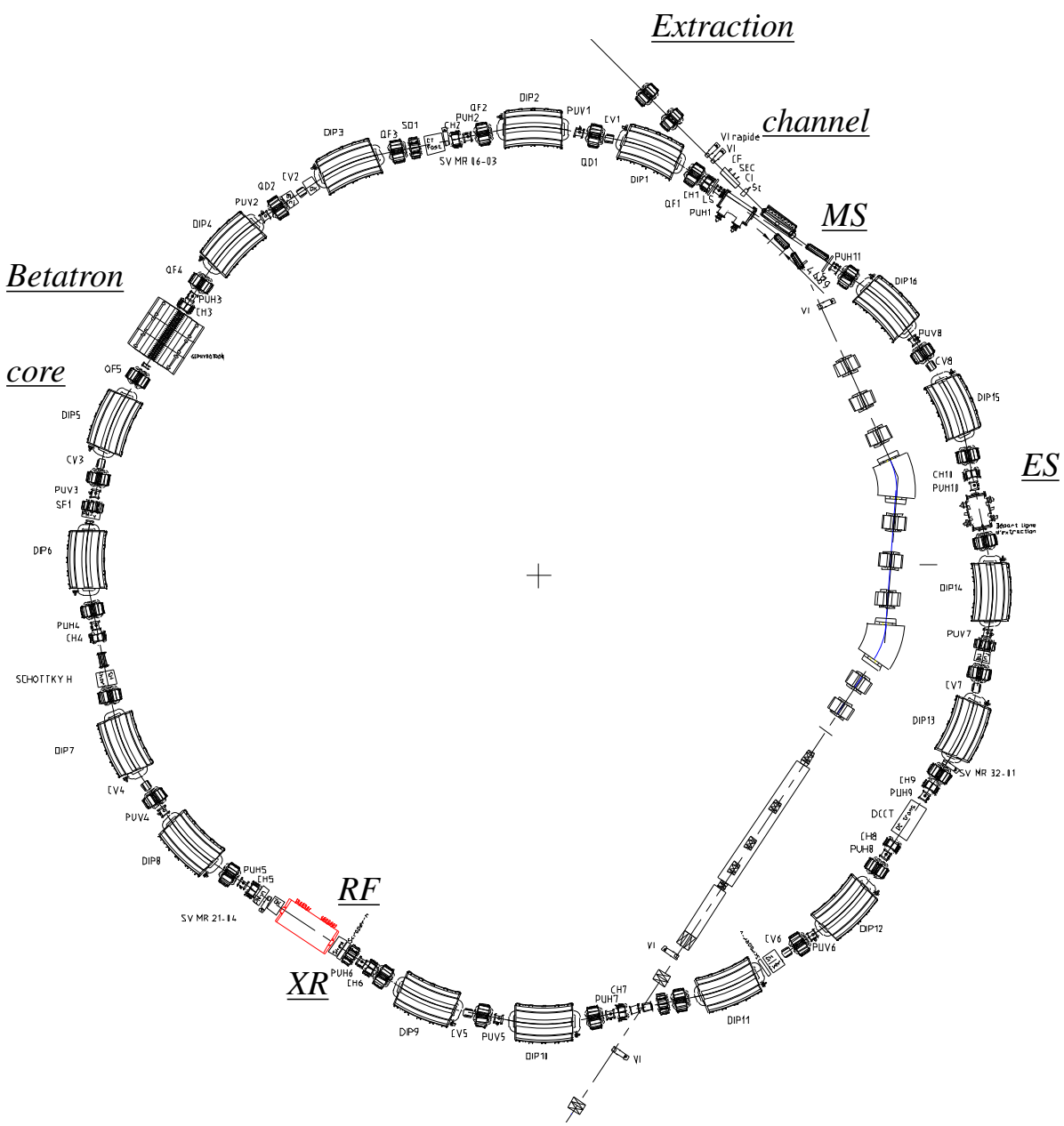
LHC undulator+long dipole SR source, and telescope. Right : Check effect on DA in LHC, using field map.





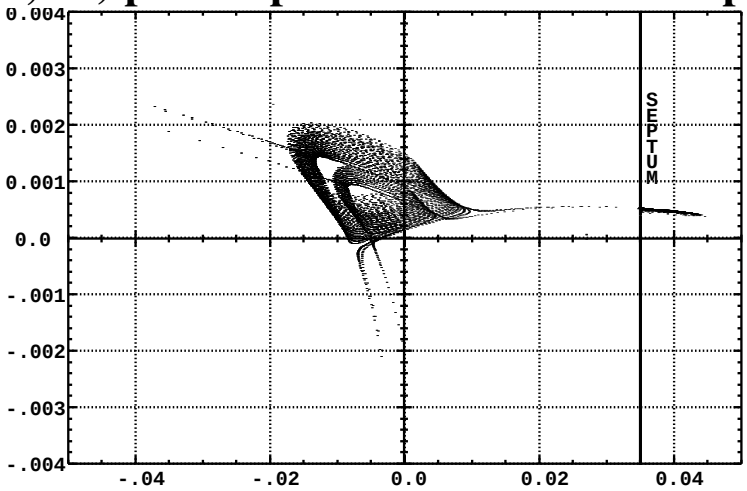
Intensity emitted (horizontal component) by 1 TeV protons, λ = 500 nm, with a distance d = 1 m between the two sources, simulated with Zgoubi (left) and with SRW (right).

2 SLOW EXTRACTION FROM PIMMS



- **Geometry/magnetism :**
- **$\mathcal{C}$ = 75.24 m ; 8 FODOF ; 2 superP**
- **16 bends, B$\leq$1.5 T, ρ=4.23 m**
- **24 quads, G$\leq$3.65 T/m**
- **4(ξ) + 1(Xtr) sextupoles**
- **$B\rho$-max = 6.35 T.m (C, 400 MeV/u)**
- **Injection equipement : electrostatic septum, 2 c.o.-bump dipoles**
- **Extraction equipement : sextupole, betatron, electrostatic septum, 2 magnetic septa**
- **Optics :**
- **nominal tunes 1.68/1.72**
- **natural $\delta\nu_{x,z}/\delta p/p = -0.6/-1.8$, $\delta\nu_{x,z}/\delta p/p = -3.5$ at injection**
- **Beam :**
- **emittances stored at injection $\epsilon_{x,z}/\pi = 30$ mm.mrad, $\delta p/p = \pm 1.2\,10^{-3}$ (p : $3.4\,10^{10}$, C : $8\,10^{8}$ particles)**
- **extracted emittances, p or C, $\epsilon_x/\pi = 0.2$ mm.mrad, $3.5 \leq \epsilon_z/\pi \leq 7$ mm.mrad, $\delta p/p = 10^{-3}$**

• **(X, X') phase-space at extraction E-Septum**



Maximum stable invariant :

$$\mathbf{A}/\pi = 48\pi\sqrt{3}\left(\frac{\nu_{\mathbf{x}}-\nu_{\mathbf{x,R}}}{\mathbf{S}}\right)^2$$

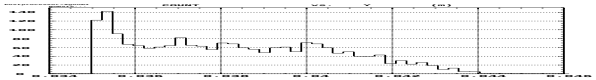
$\Delta X \sim SX^2 \Rightarrow$ **spiral step :** $\boxed{\mathbf{S}}$

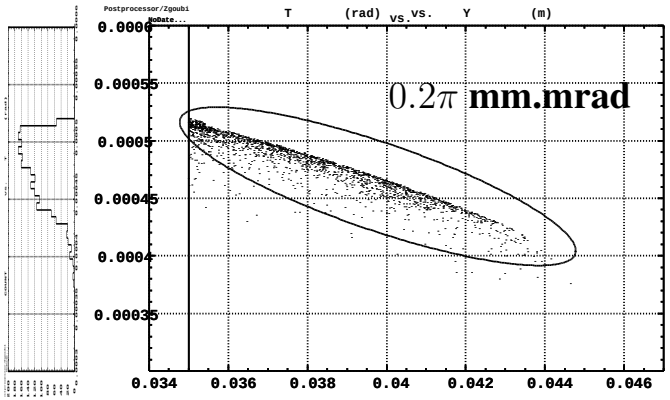
Alignement of separatrices :

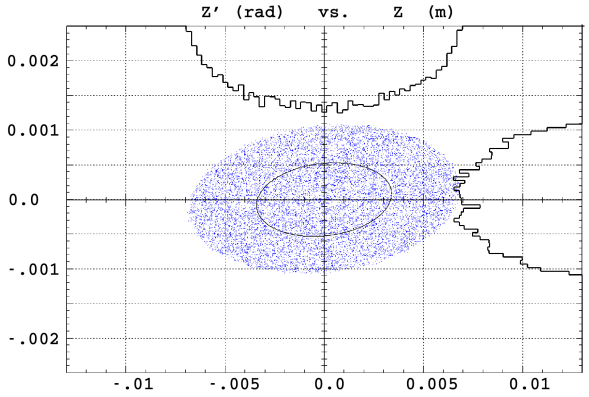
$$\frac{\alpha D_x+\beta D'_x}{\sqrt{\beta}}\sin(\phi+\frac{\pi}{3})+\frac{D_x}{\sqrt{\beta}}\cos(\phi+\frac{\pi}{3})\Big|_{ES} = -\frac{4\pi}{S}\,\boxed{\xi_x}$$

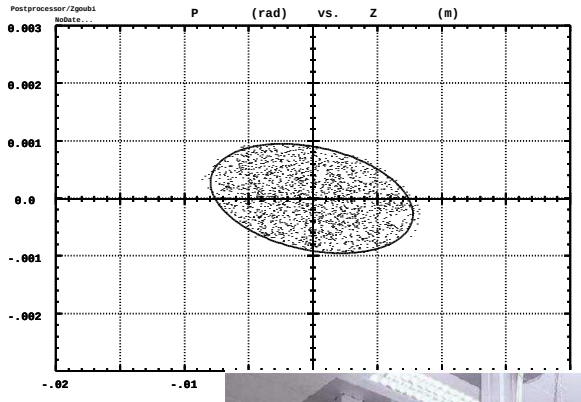
• **AT SEPTUM: Extracted (X, X')** **periodic (Z, Z')** **extracted (Z, Z')**

(same area, tilted due to chromaticity)

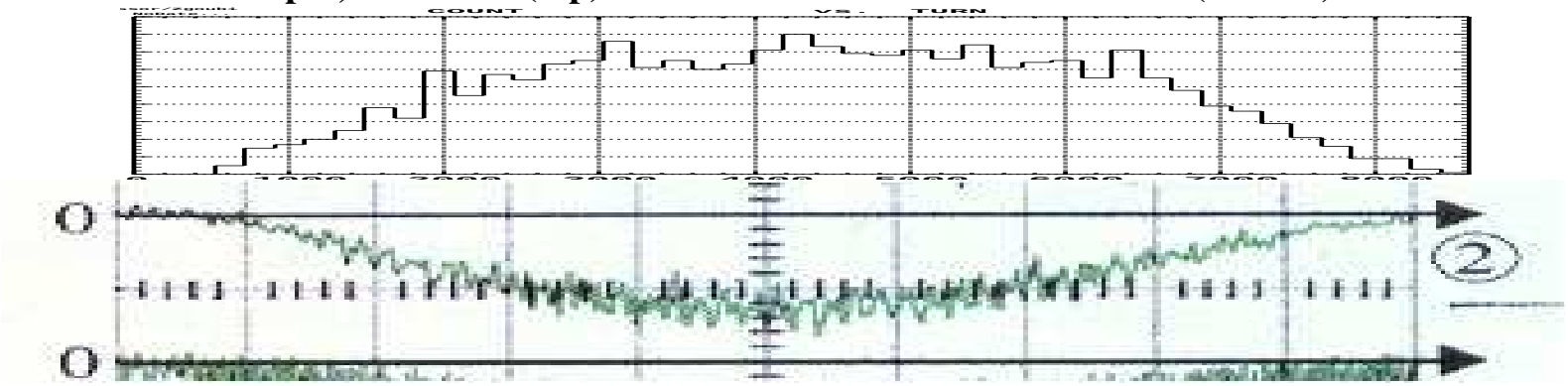




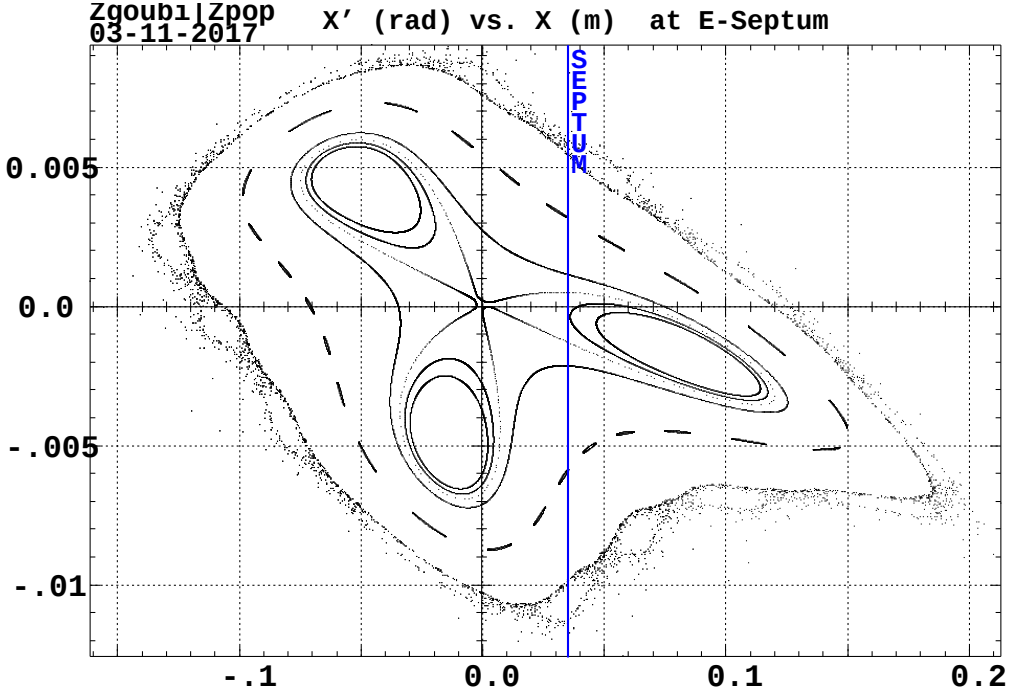




• **Spill, simulated (top) and from measurements at Saturne (bottom) :**

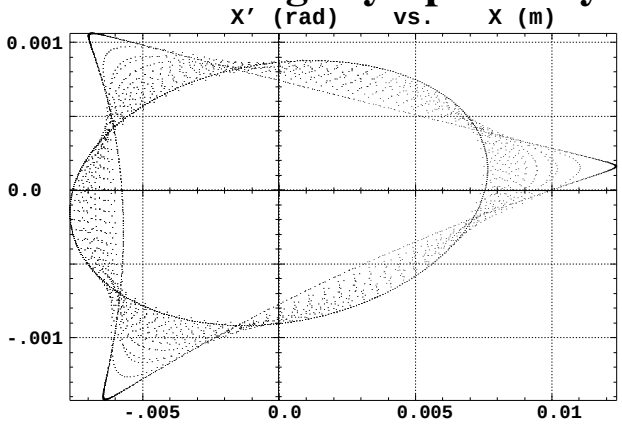


- **Ray-tracing has all non-linearities: field, kinenatic**
  It has the right field models.



20,000 turns in PIMMS, 5 particles on different invariants

- **Appropriate integration step size ensures high symplecticity:**

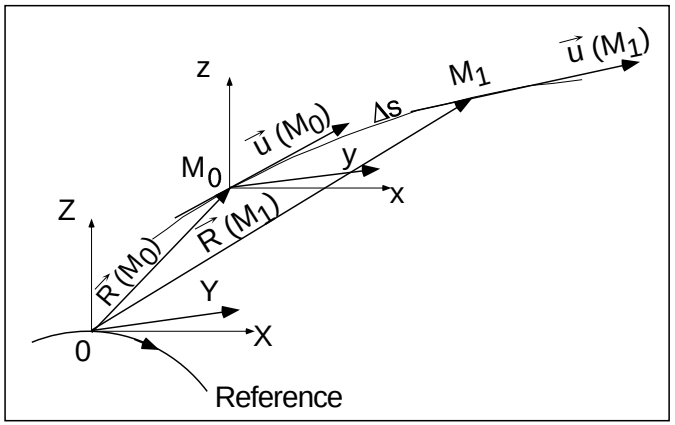


Adiabatic switch on of XR, from ellipse to triangle, followed by switch off, from triangle back to ellipse.

- **The integrator in these ray-tracing examples :**

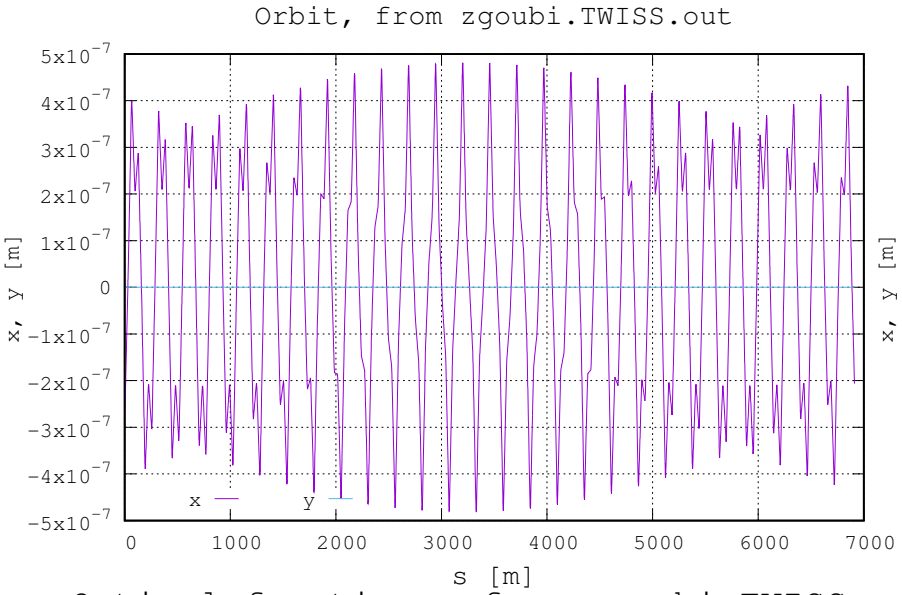
$$\text{Position} \;:\; \vec{\mathbf{R}}(\mathbf{M_1}) \approx \vec{\mathbf{R}}(\mathbf{M_0}) + \vec{\mathbf{u}}(\mathbf{M_0})\,\mathbf{\Delta s} + \vec{\mathbf{u}}'(\mathbf{M_0})\,\frac{\mathbf{\Delta s^2}}{\mathbf{2!}} + \ldots$$

$$\text{Velocity} \;:\; \vec{\mathbf{u}}(\mathbf{M_1}) \approx \vec{\mathbf{u}}(\mathbf{M_0}) + \vec{\mathbf{u}}'(\mathbf{M_0})\,\mathbf{\Delta s} + \vec{\mathbf{u}}''(\mathbf{M_0})\,\frac{\mathbf{\Delta s^2}}{\mathbf{2!}} + \ldots$$

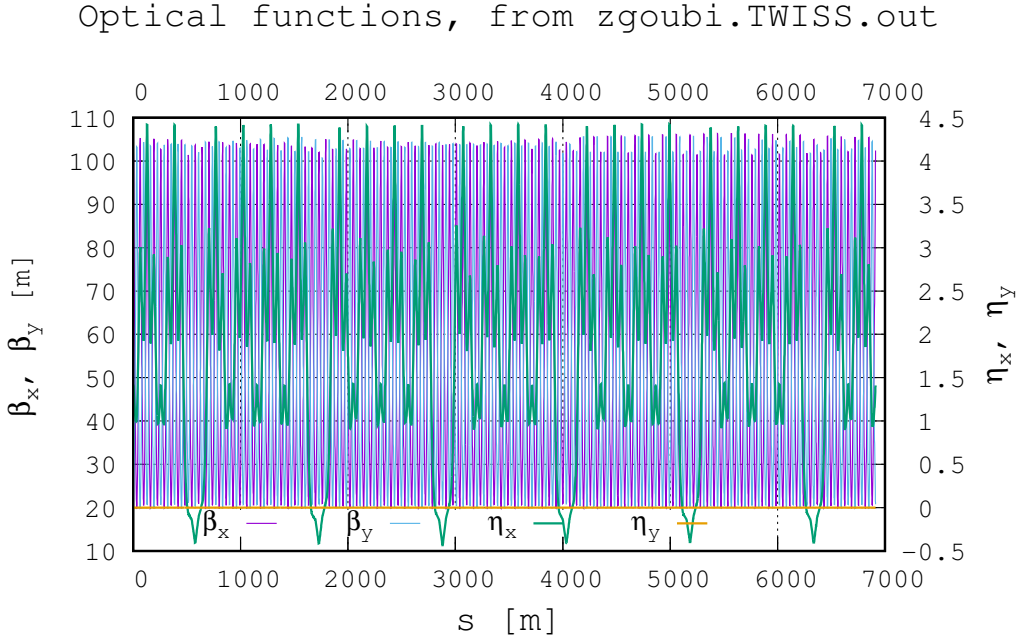


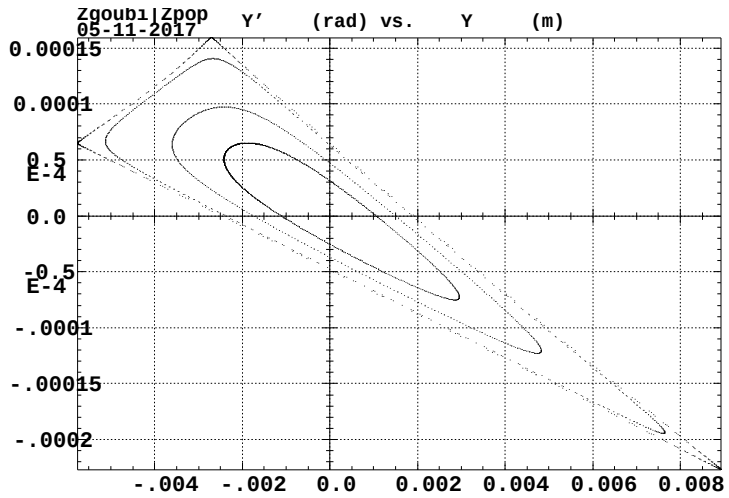
3 SLOW EXTRACTION AT SPS - IN COLLABORATION WITH LINDA STOEL

- **Zgoubi files are translated from MADX's**
- **No orbit bump**

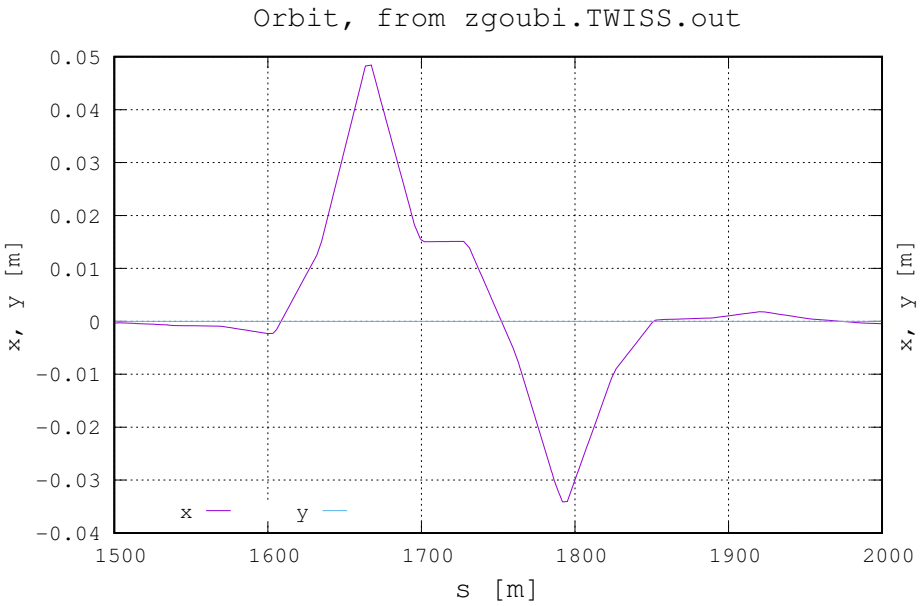



```
@ LENGTH                6911.517671
@ Q1                    0.6666653177        [fractional]
@ Q2                    0.5799997167        [fractional]
@ DQ1                   -20.05420109
@ DQ2                    11.13014019
@ DXMAX                  4.42029428E+00     @ DXMIN
@ XCOMAX                 4.80524777E-05     @ XCOMIN
@ BETXMAX                1.04300781E+02     @ BETXMIN
@ BETYMAX                1.05137881E+02     @ BETYMIN
@ XCORMS                 2.52010649E-05
@ DXRMS                  1.29280574E+00
@ TITLE                  "Zgoubi model"
```





• Extraction orbit bump set



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@	Q2	0.5539174340
@	DQ1	-24.28317516
@	DQ2	14.55285663
@	DXMAX	4.54923157E+00
@	XCOMAX	4.84068171E+00
@	BETXMAX	1.27810268E+02
@	BETYMAX	1.34213522E+02
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@	DXRMS	1.28735669E+00
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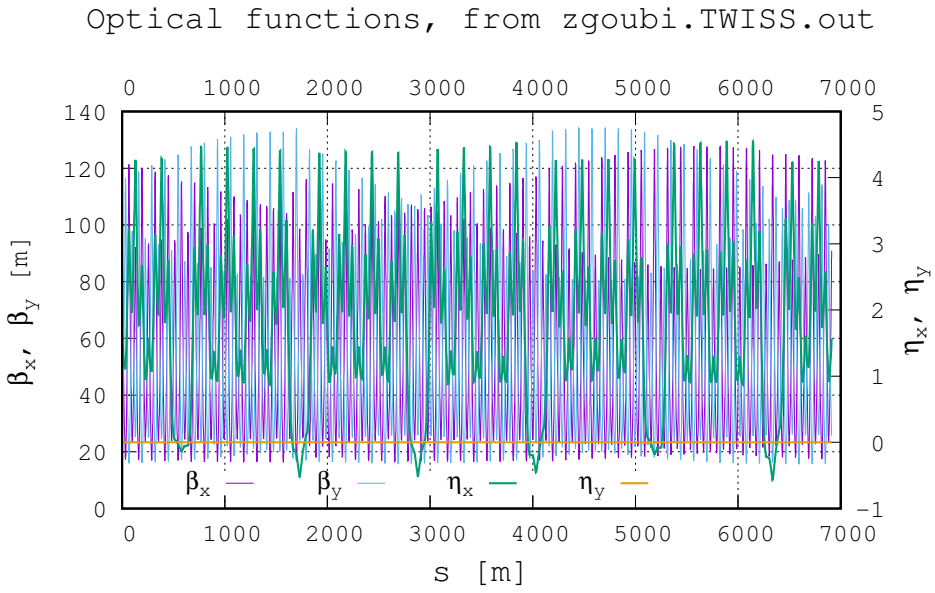
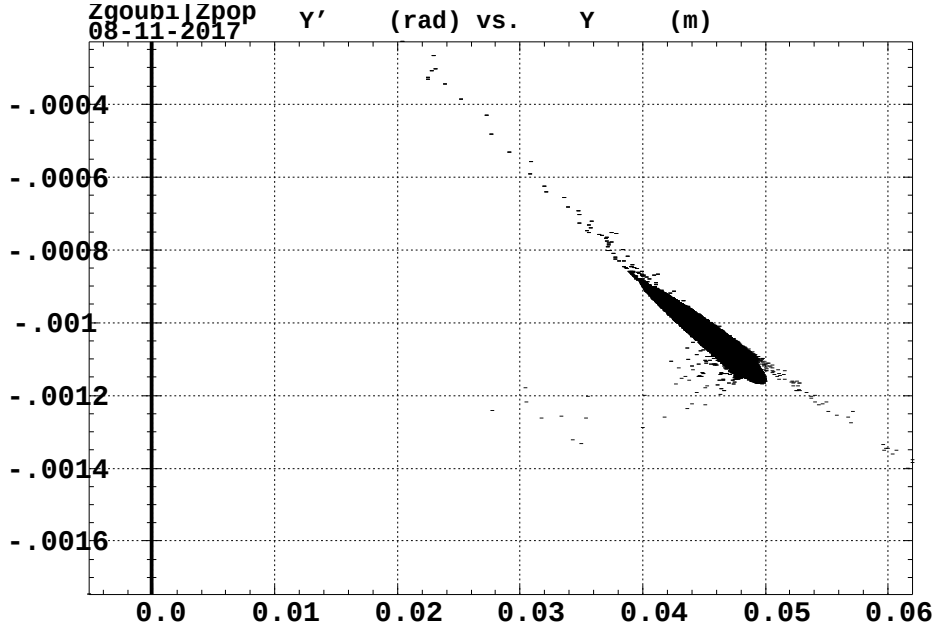
@	ORIGIN	"twiss.f"





- **CPU time (1 cm step in all magnets) :**
  - **$<$0.15s/turn**
  - **4hrs overnight $\rightarrow$ 96,000 turns**
  - **6600m/3e8=22mus/turn $\rightarrow$ simulates 2 seconds**

- **A MADX $\longrightarrow$ Zgoubi translator specific to SPS lattice is operational**
- **It "remains" to fine-tune various parameters to their correct values (rather than those I may have used for this installation), that includes :**
  - **range of tune sweep**
  - **number of turns of the extraction**
  - **strength of extraction sextupoles**
  - **orbit bump and its excursion at AP.UP.ZS.21633**

- **Power supply rack in Zgoubi :**

```
 'SCALING'
1  12
MULTIPOL QF*  ! THIS SWEEPS QX FROM 26.6366 TO 26.6966
2       !  .6366/.58 -> .6966/.58
0.99980849    1.0011416        ! FIT# 20
1             200
MULTIPOL QD*
2       !  .6366/.58 -> .6966/.58
0.99923000    0.99945205        ! FIT# 24
1             200
MULTIPOL LSE.10602 LSE.22402 LSE.40602 LSE.52402
-1
-0.011992     ! STRENGTH OF EXTRACTION SEXTUPOLES
1
MULTIPOL LSFA* LSFC*
-1
1.8523957     ! CHROMATICITY SEXTUPOLES
1
MULTIPOL LSFB*
-1
0.28461842
1
MULTIPOL LSDA*
-1
1.0090368
1
MULTIPOL LSDB*
-1
1.0458254
1
MULTIPOL RB_*    ! ORBIT BUMP AMPLITUDE
-1
.4725  ! for 4.368cm at E-septum
1
```

THANK YOU FOR YOUR ATTENTION