Status of MERLIN and Recent Developments

Haroon Rafique

On behalf of the MERLIN group:

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In Collaboration with CERN:

R. Bruce, A. Santamaría, S. Redaelli, J. F. Wagner

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MERLIN

LHC Collimation using MERLIN

HEL process

CC Failure process

What next?

MERLIN

MERLIN

C++ Accelerator Physics Library (N. Walker @ DESY, storage ring functionality added by A. Wolksi)

User writes their own simulation containing:

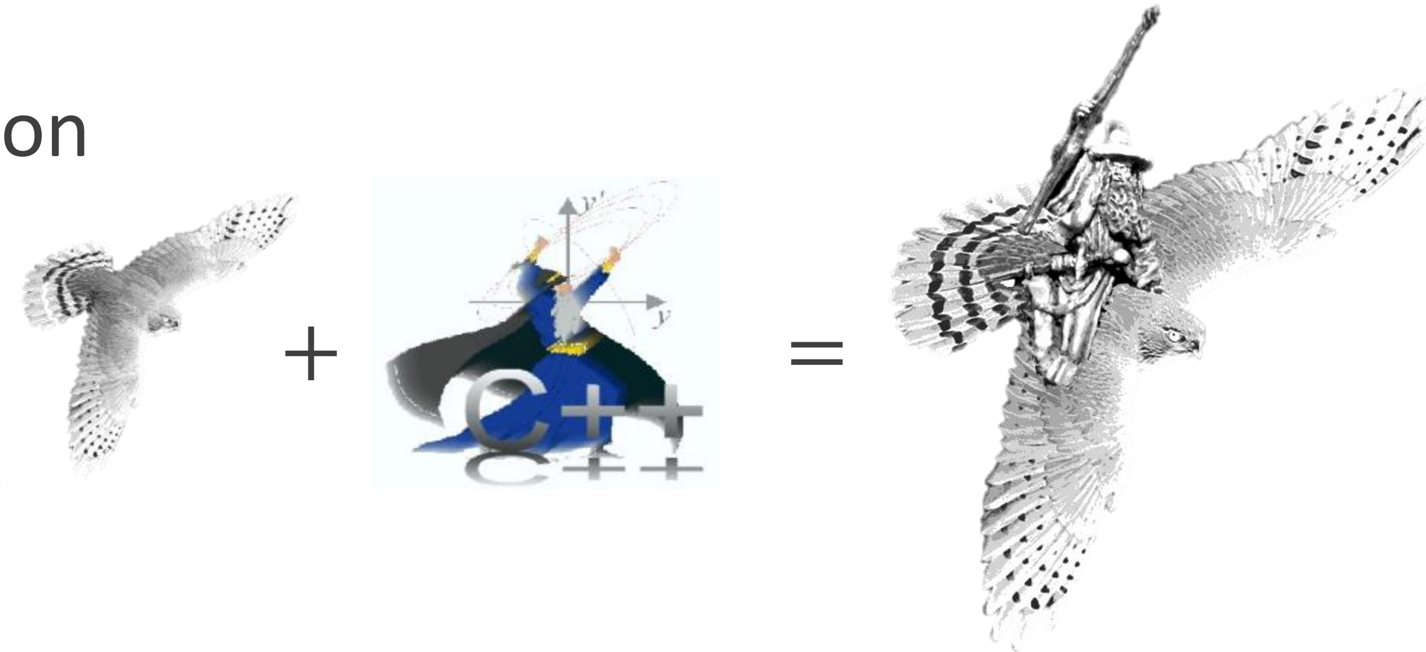
- Beam -> **Bunch**
- **Accelerator Model** (MAD .tfs table)
- **Tracker** (different integrators available)
- Physics Processes (user defined / pre existing)

Modular – **easier** to use

Extensible – if you have the physics, adding a process is trivial

Merge

- Consolidation of processes:
  - Collimation (scattering, binning, etc)
  - Hollow Electron Lens (HEL)
  - Crab Cavity Failure
- Clean up
- Optimisation
- Test suite
- Cmake
- Git history



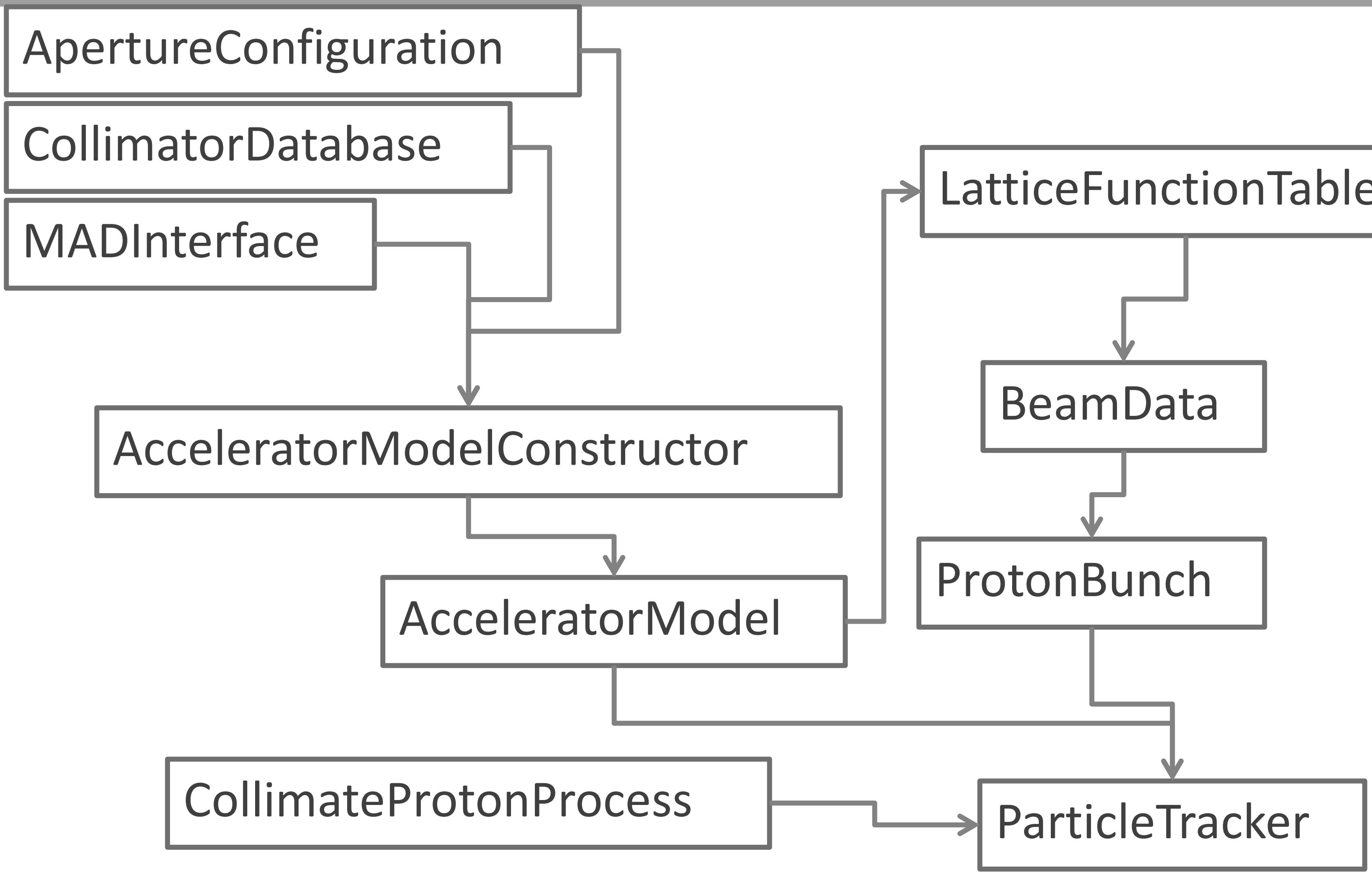
Former Developers

Thanks to all:

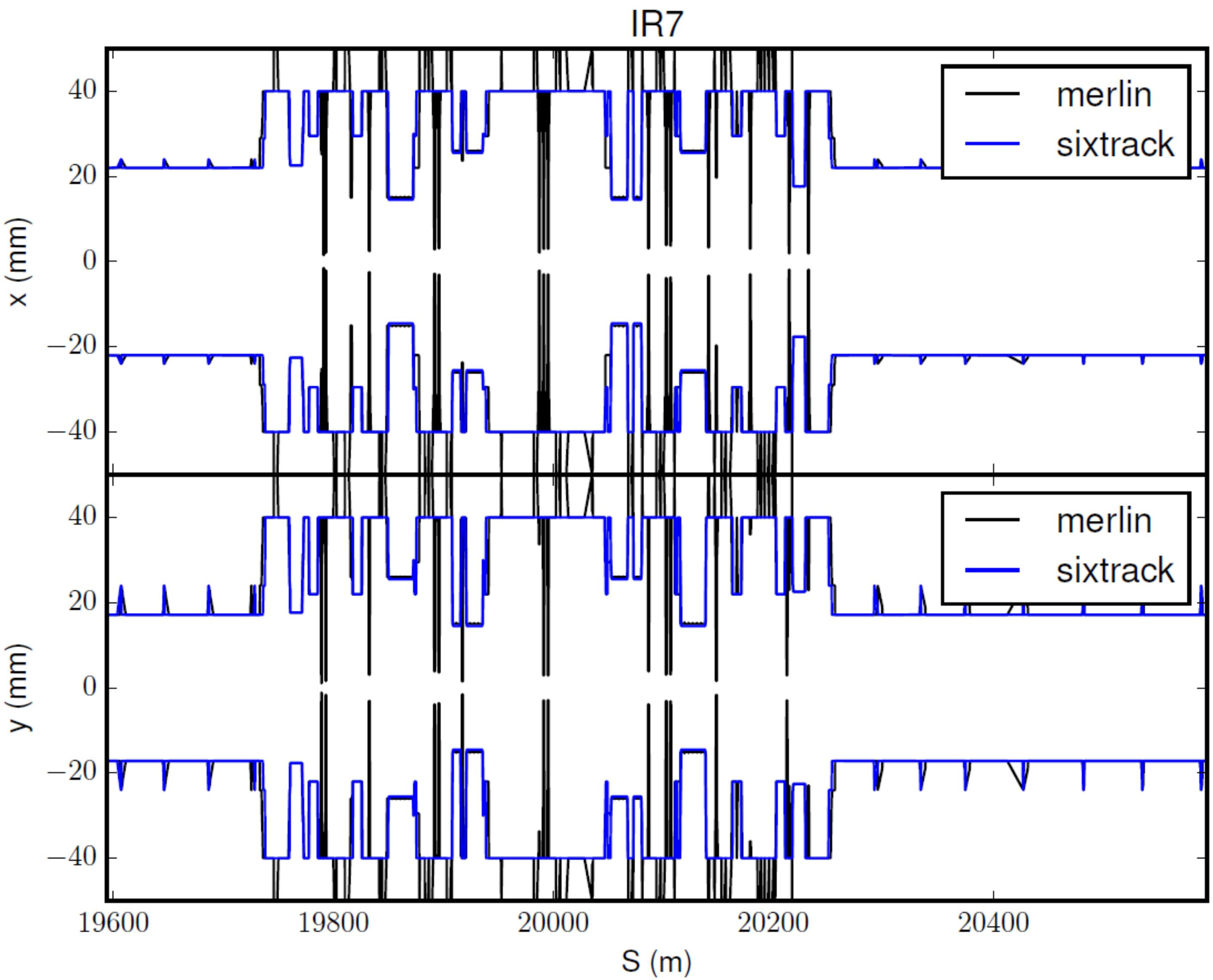
• James Molson	[Manchester]
• Maurizio Serluca	[Manchester]
• Adina Toader	[Manchester]
• Adriana Bungau	[Manchester]
• Andy Wolski	[Liverpool]
• Others …?	
• Dirk Krücker	[DESY]
• Nick Walker	[DESY]

COLLIMATION USING MERLIN

Typical User Code

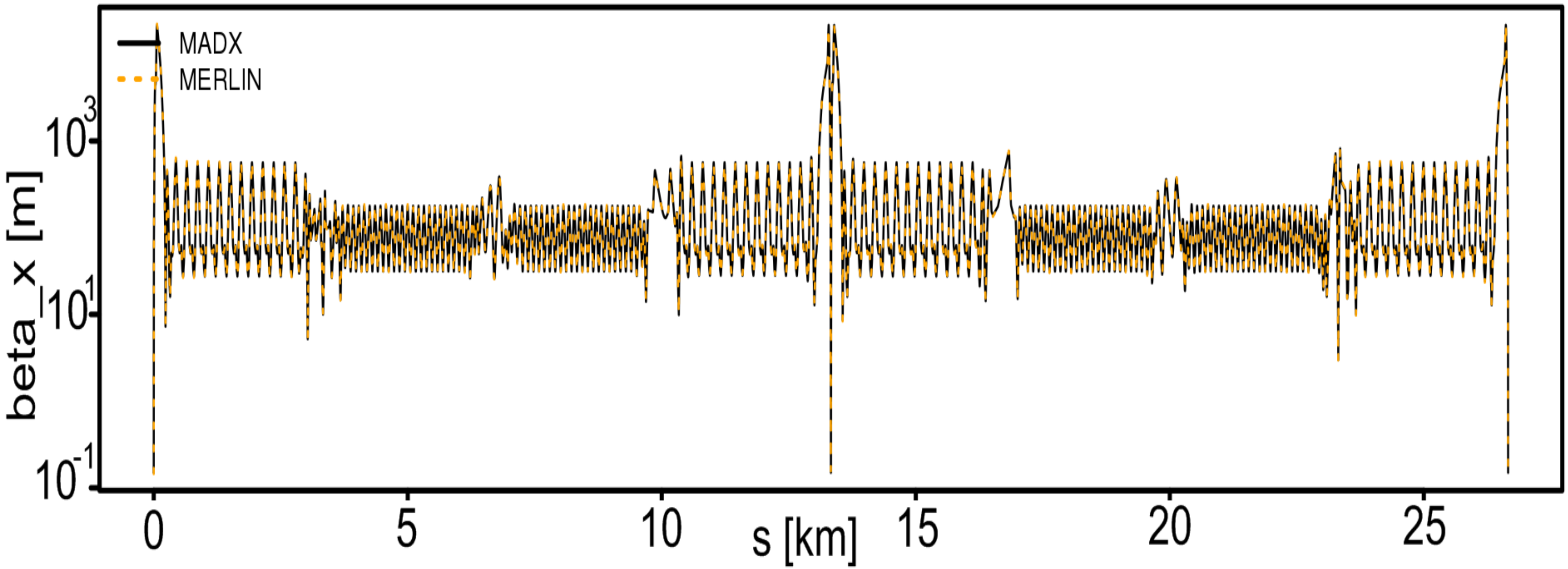


Apertures



IR7
merlin
sixtrack
x (mm)
y (mm)
40
20
0
−20
−40
19600
19800
20000
20200
20400
S (m)

HL LHC Optics



Integrator

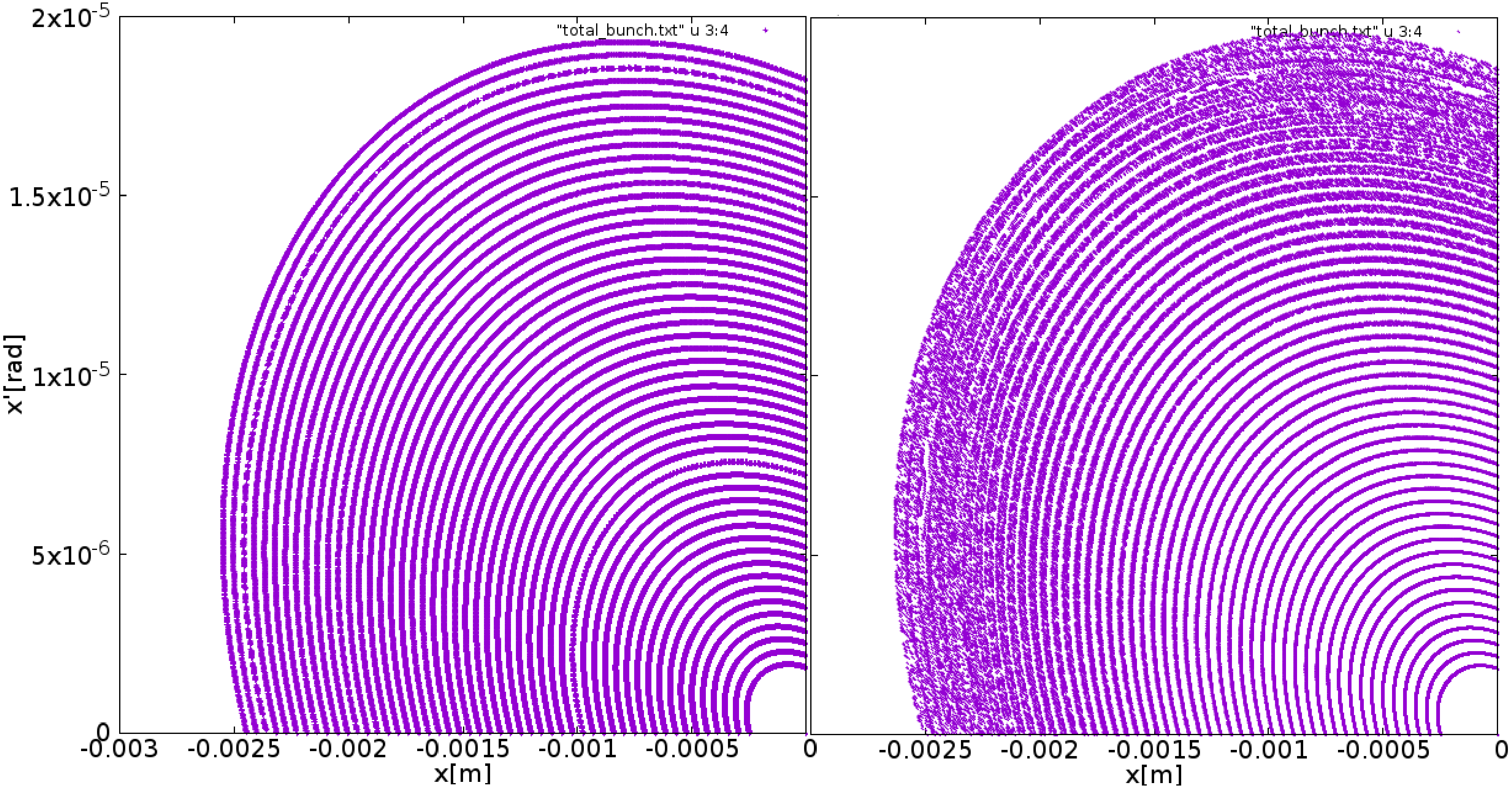
MERLIN includes 3 standard integrator sets:

1. TRANSPORT
2. SYMPLECTIC
3. THIN_LENS

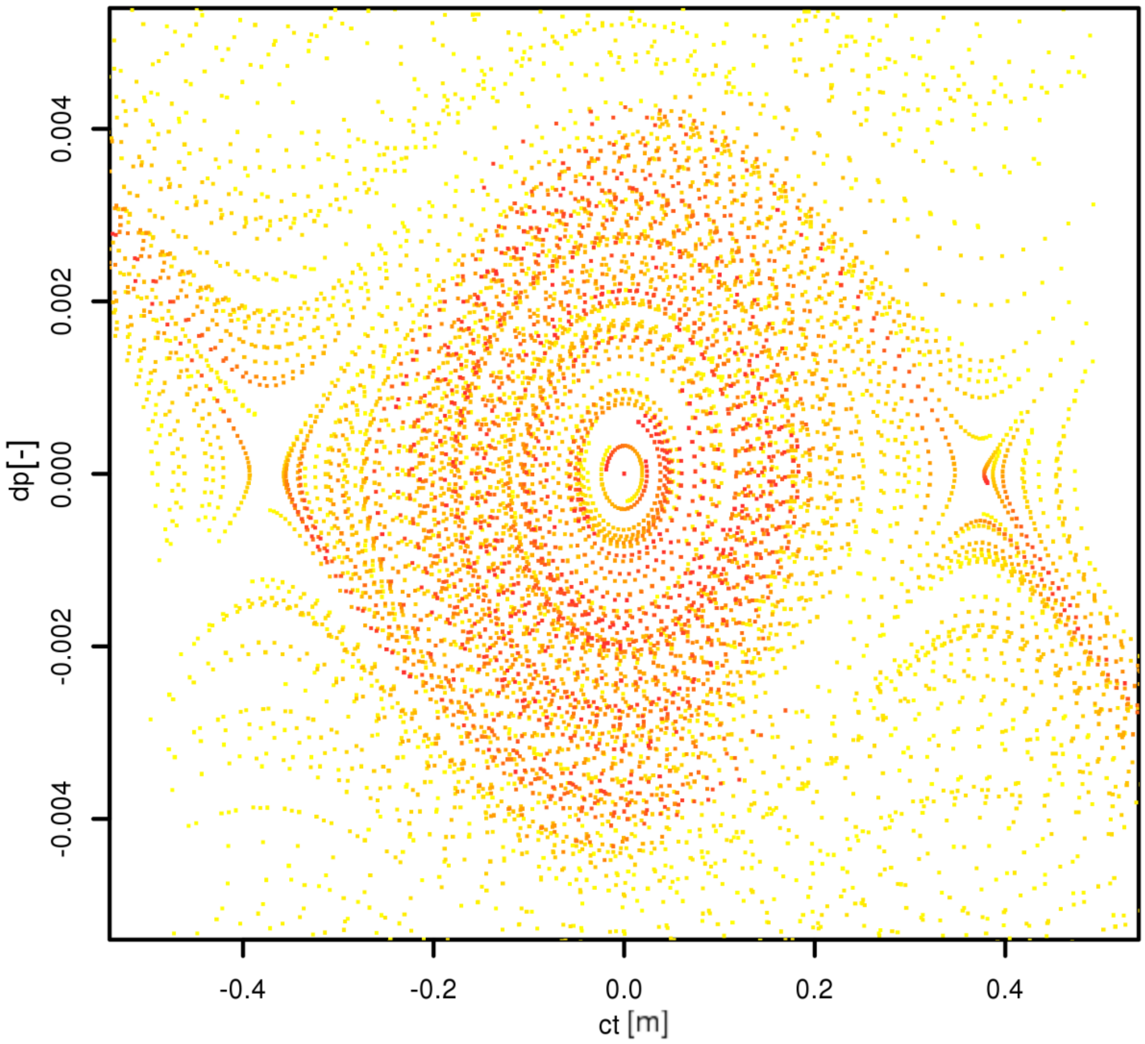
```
myParticleTracker->SetIntegratorSet (new ParticleTracking::SYMPLECTIC::StdISet());
myParticleTracker->SetIntegratorSet (new ParticleTracking::TRANSPORT::StdISet());
```

```
Legend:
Class
User object
Function
Variable
```

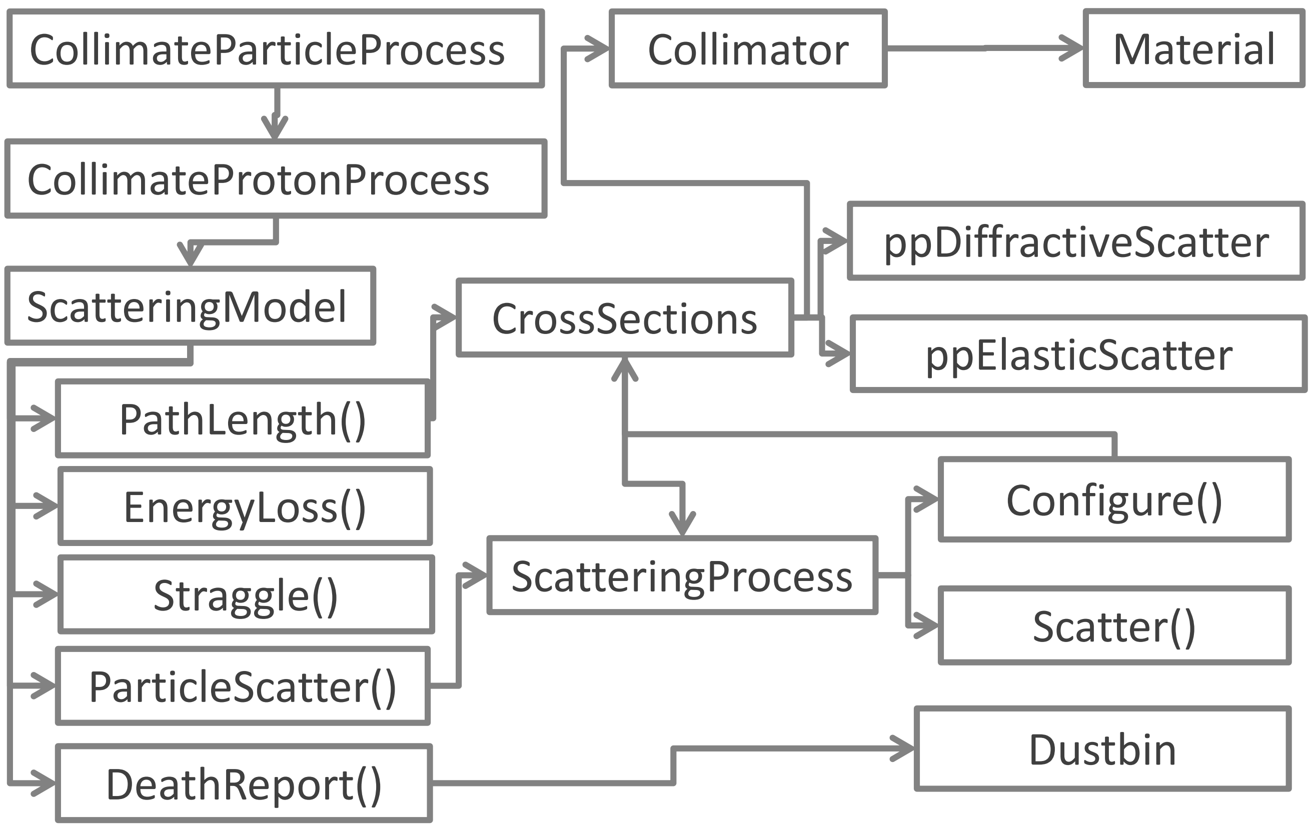
TRANPSORT vs SYMPLECTIC



Synchrotron Motion



Collimation Process



Scattering Processes

SixTrack+K2 – like & MERLIN scattering for:

- Rutherford
- Elastic pn
- Elastic pN
- SD
- Inelastic

Merlin

- Rutherford
- Elastic pn
- Elastic pN
- SD
- Inelastic

SixTrack & ST + Ad. Ionisation

- ST Rutherford
- ST Elastic pn
- ST Elastic pN
- ST SD
- Inelastic

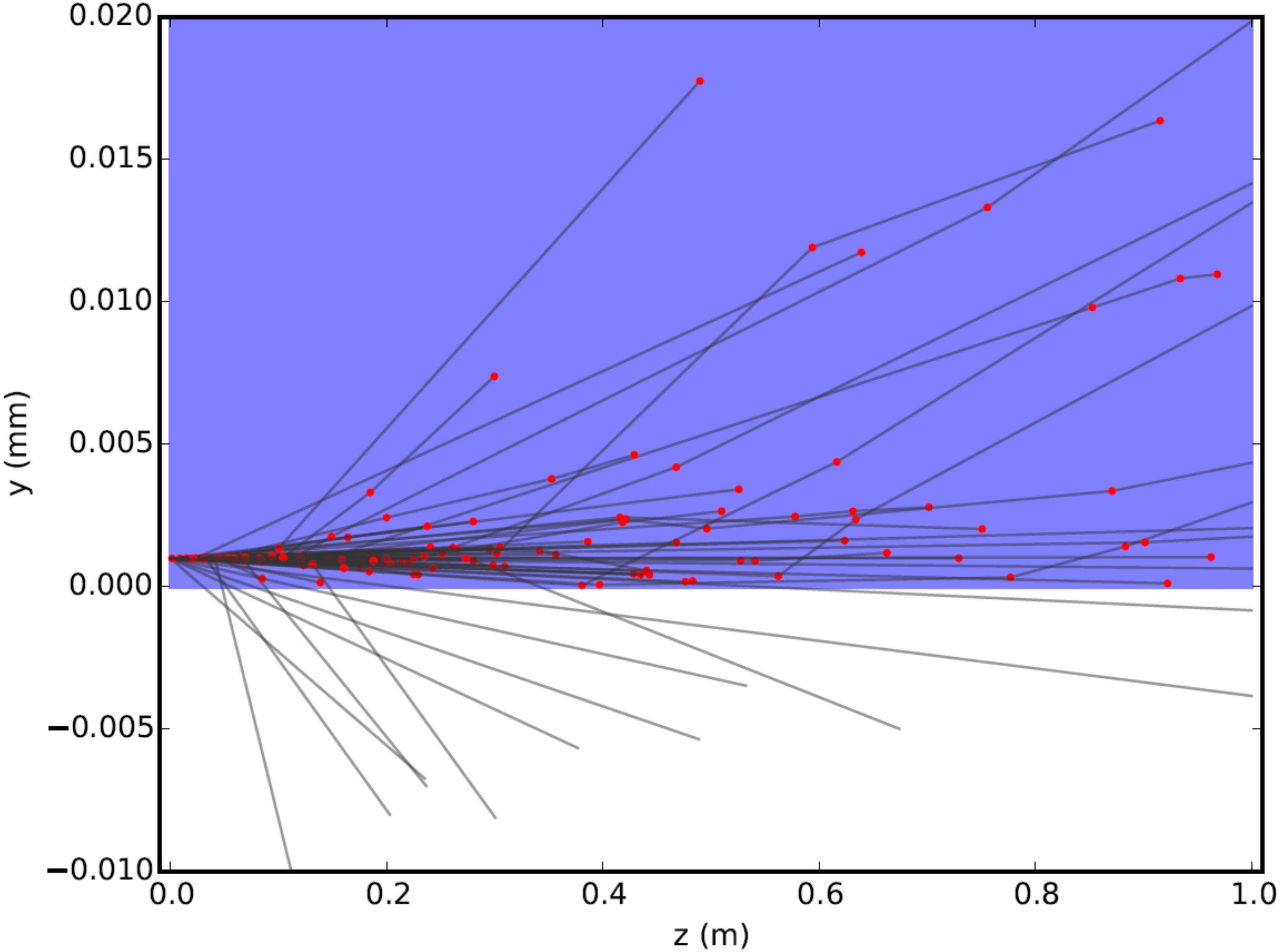
ST + Ad. Elastic

- ST Rutherford
- Elastic pn
- Elastic pN
- ST SD
- Inelastic

ST + Ad. SD

- ST Rutherford
- ST Elastic pn
- ST Elastic pN
- SD
- Inelastic

Scattering



HOLLOW ELECTRON LENS PROCESS

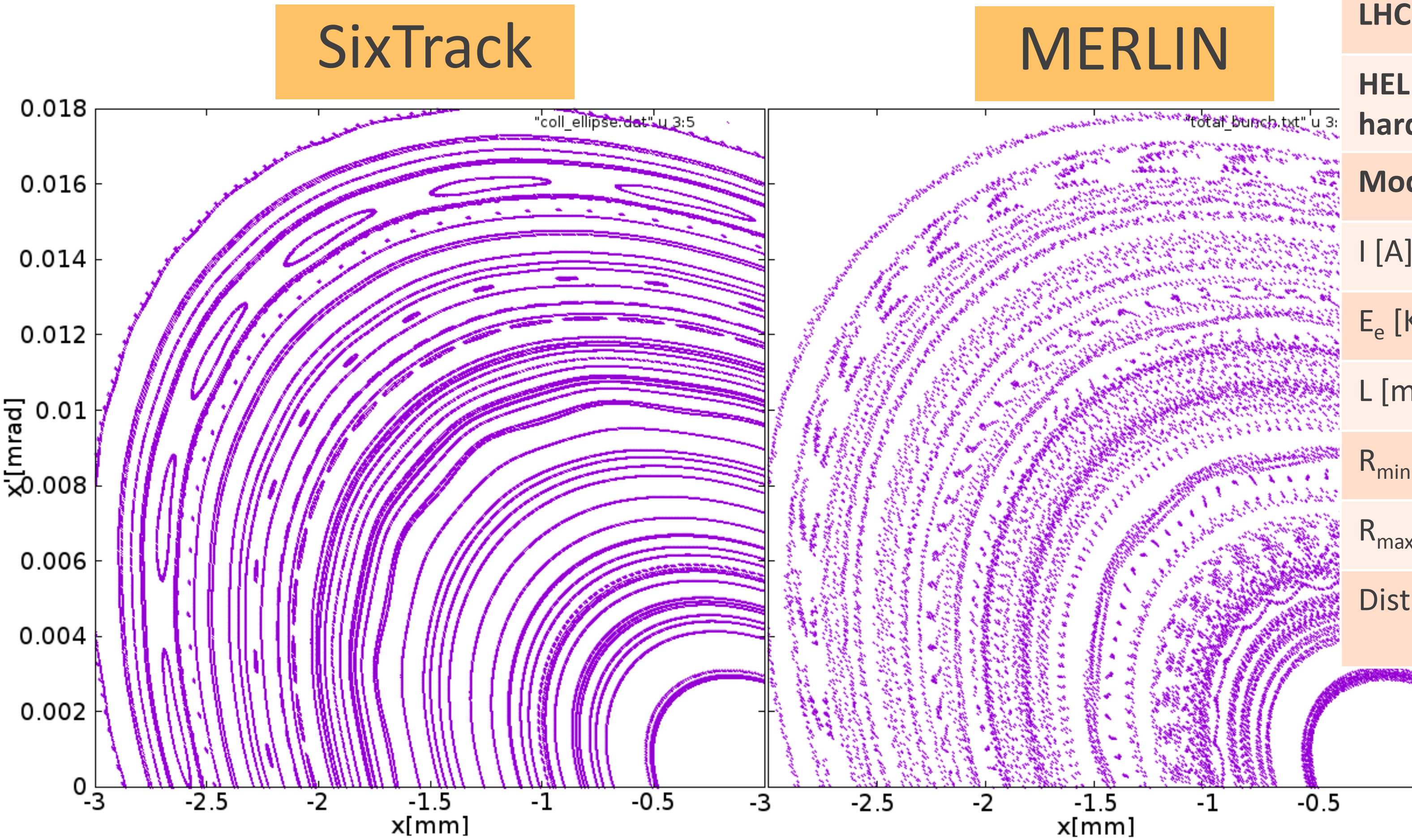
HR & Joschka Wagner @ CERN

Poincaré Sections

- HEL @ s = 10037 m (40m downstream of IP4) in LHC lattice (RB46)
- $10^4 - 10^5$ turns in the LHC
  - Nominal v6.503, HL v1.2
- Output particle data @HEL position every turn
- Plot *xx'* phase space to see effect

SixTrack vs MERLIN: DC

Identical SixTrack bunch



Parameter	Value
LHC lattice	**Nominal**
HEL hardware	**Tevatron**
Mode	**DC**
I [A]	1.2
E_e [KeV]	5
L [m]	2
R_{min} [σ_x]	4
R_{max} [σ_x]	6.8
$Dist^n$	SixTrack 1-10 σ_x

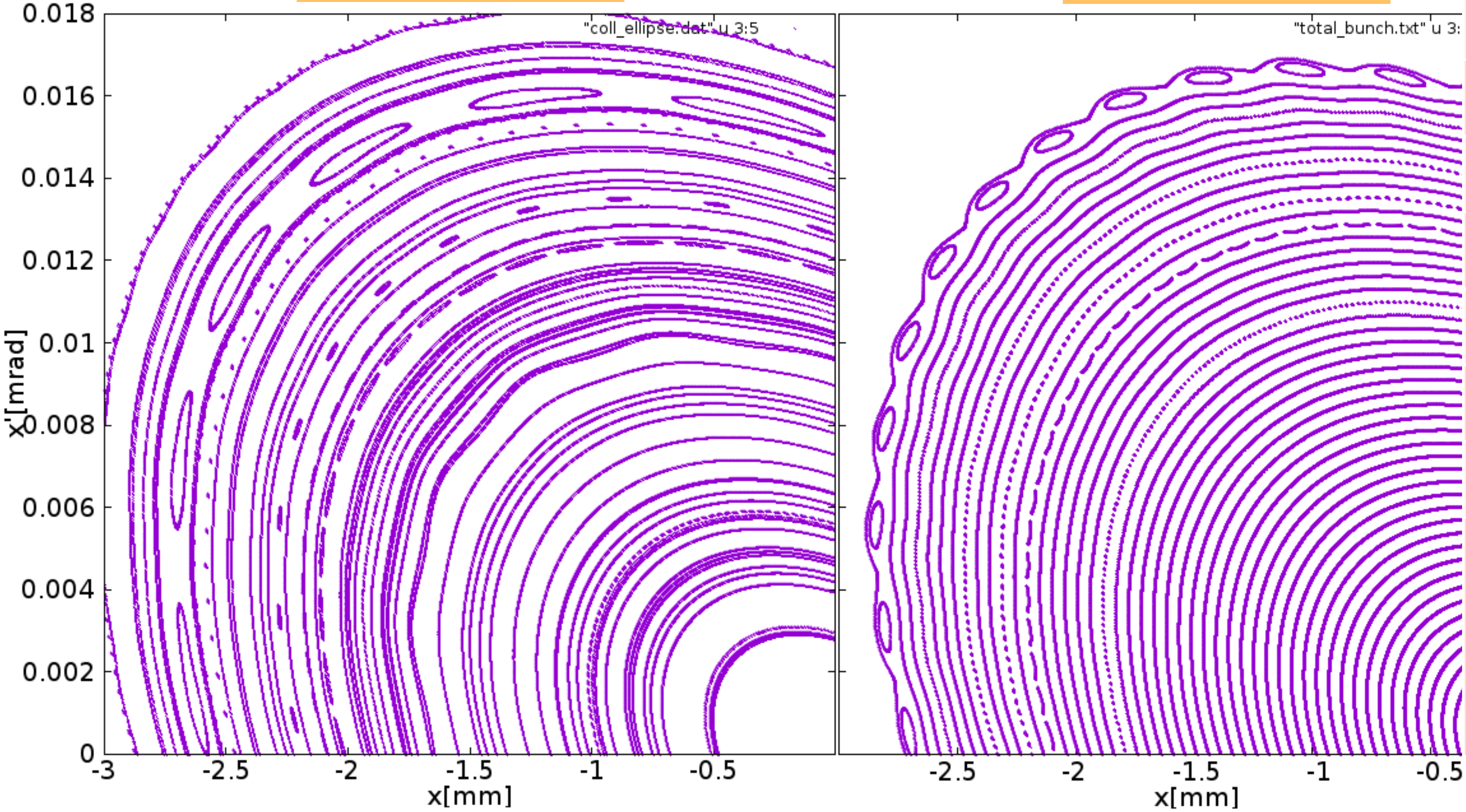
$4\sigma_x \approx 1.17$ mm

SixTrack vs MERLIN: DC

Different initial bunch for clarity

SixTrack (using SixTrack bunch)

MERLIN (using MERLIN bunch)



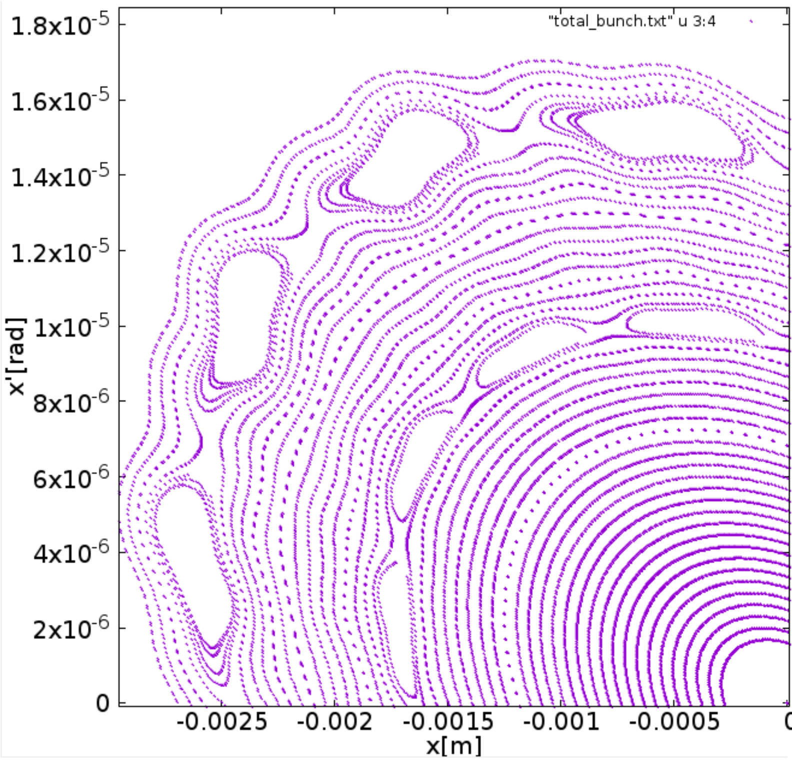
Parameter	Value
LHC lattice	Nominal
HEL hardware	Tevatron
Mode	DC
I [A]	1.2
E_e [KeV]	5
L [m]	2
R_{min} [σ_x]	4
R_{max} [σ_x]	6.8
Dist^n	SixTrack (Left) MERLIN (Right) 1-10 σ_x

$4\sigma_x \approx 1.17$ mm

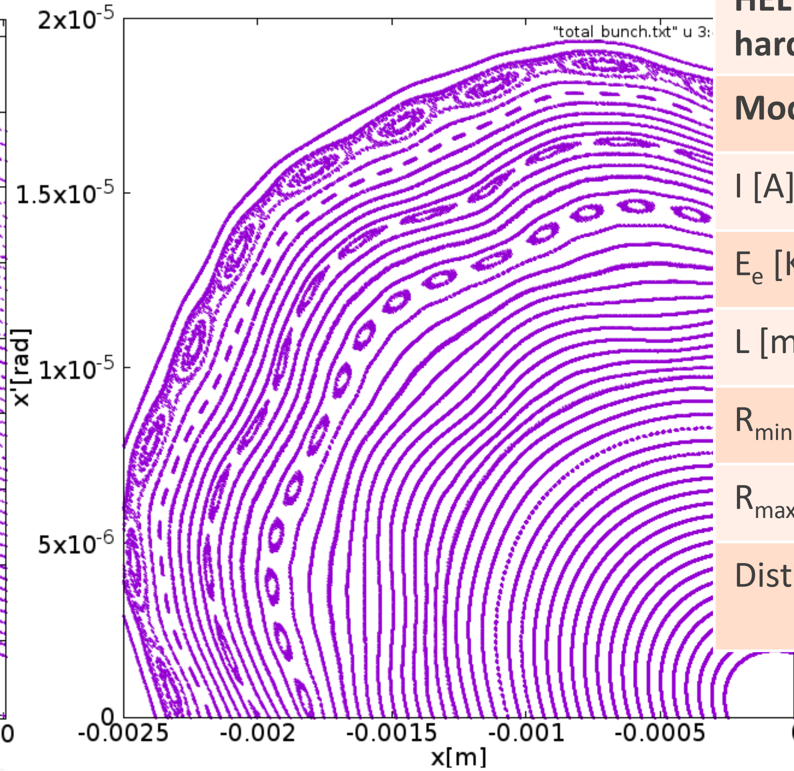
Nominal vs HL LHC: DC

Identical MERLIN bunch

MERLIN nominal



MERLIN HL



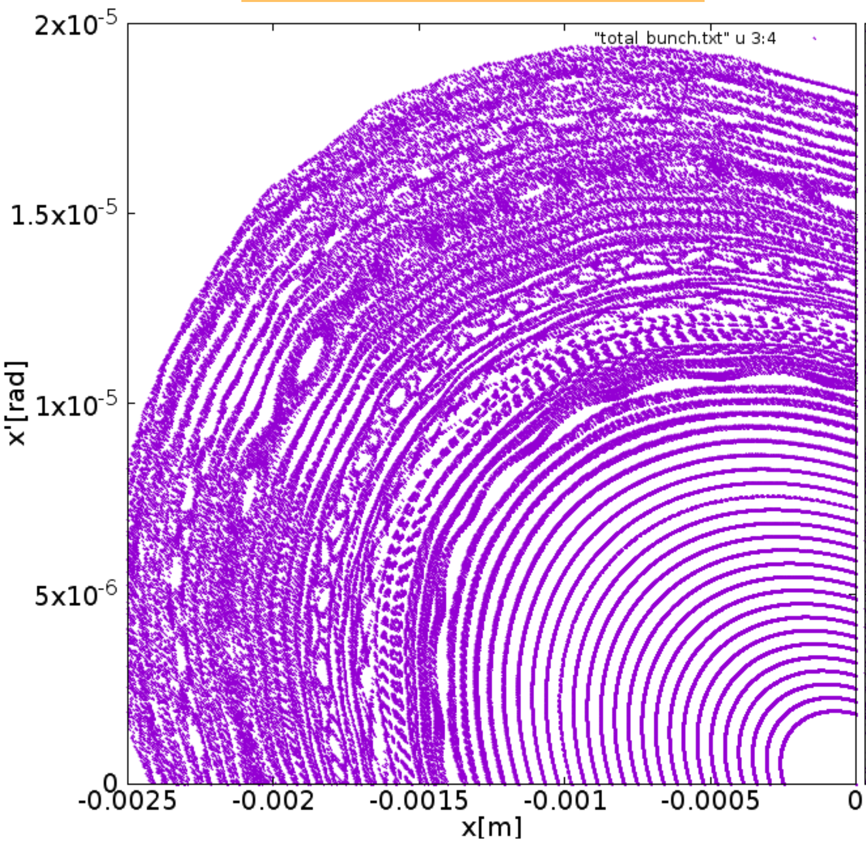
Parameter	Value
LHC lattice	Nominal (left) HL (right)
HEL hardware	LHC
Mode	DC
I [A]	5
E_e [KeV]	10
L [m]	3
R_{min} [σ_x]	4
R_{max} [σ_x]	8
Dist^n	MERLIN 1-10 σ_x

HL LHC: AC vs Diffusive

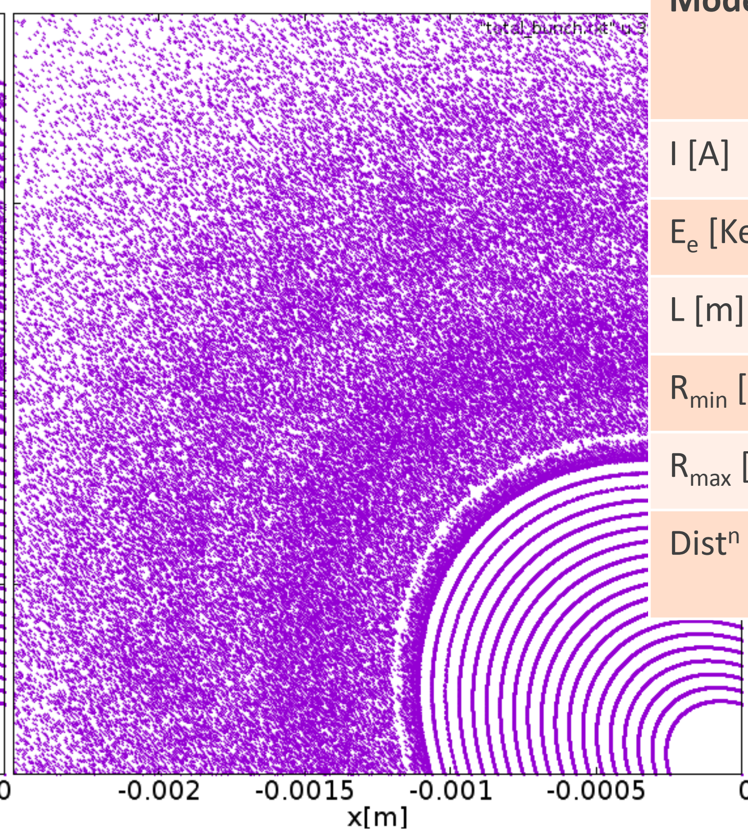
Identical MERLIN bunch

Parameter	Value
LHC lattice	**HL**
HEL hardware	**LHC**
Mode	**AC (left) Diffusive (right)**
I [A]	**5**
E_e [KeV]	**10**
L [m]	**3**
R_{min} [σ_x]	4
R_{max} [σ_x]	**8**
$Dist^n$	MERLIN 1-10 σ_x

AC

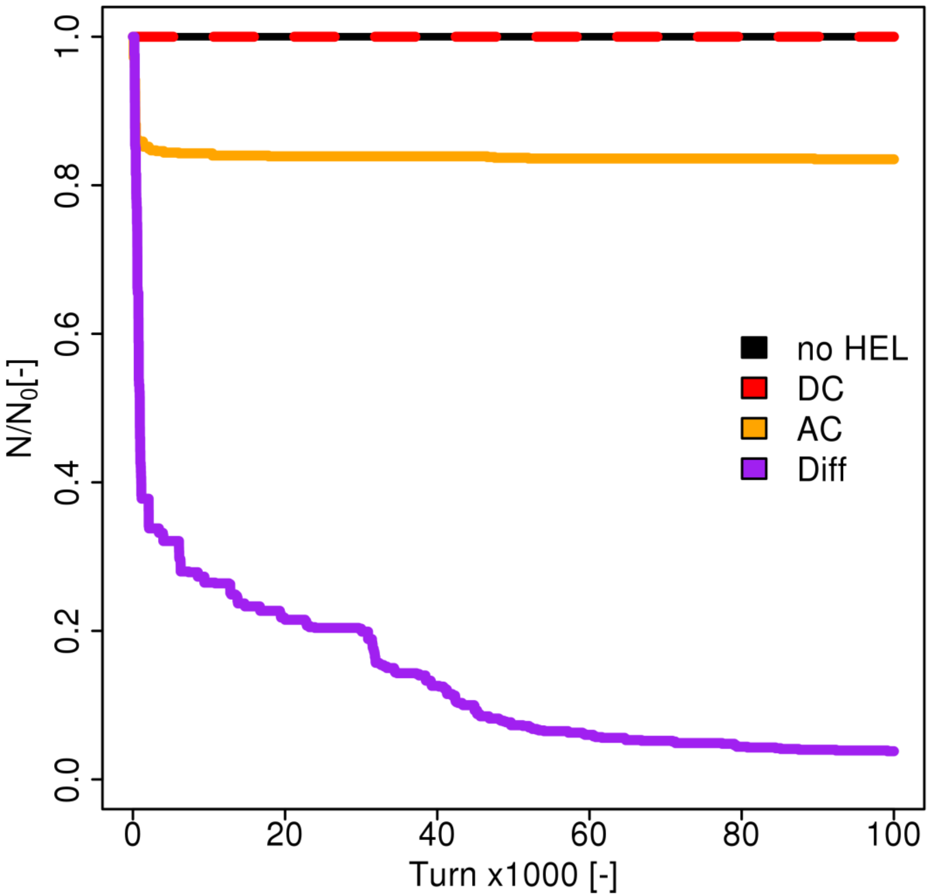


Diffusive

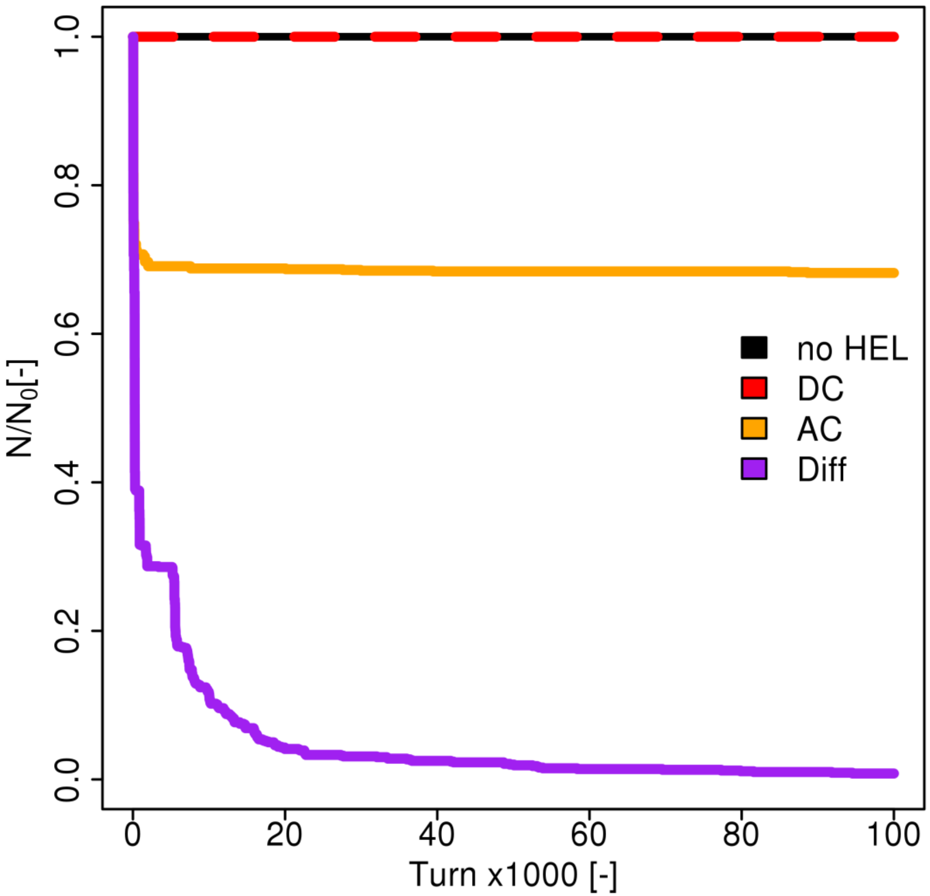


Cleaning: nominal vs HL LHC

Nominal LHC



High Luminosity LHC



CRAB CAVITY FAILURE PROCESS

HR & Andrea Santamaria Garcia @ CERN

Simple Kick Model

Crab cabity kick

The Hamiltonian to describe a thin horizontal CC is:

$$H_{crab} = \frac{qV}{p_s} \sin\left(\phi_s + \frac{\omega z}{c}\right) x$$

So that:

$$\Delta p_x = -\frac{\partial H_{crab}}{\partial x} = -\frac{qV}{p_s} sin\left(\phi_s + \frac{\omega z}{c}\right)$$
$$\Delta p_z = -\frac{\partial H_{crab}}{\partial z} = -\frac{qV}{p_s} cos\left(\phi_s + \frac{\omega z}{c}\right)\frac{\omega}{c} x$$

Derivation of the voltage

To translate the (y, y') vector between two arbitrary points of the machine we use the tran

$$\begin{pmatrix} y_2 \\ y_2' \end{pmatrix} = M_{1\to2} \begin{pmatrix} y_1 \\ y_1' \end{pmatrix}$$

In terms of the Twiss paramenters and the phase advance between the points we have:

$$M_{1\to2} = \begin{pmatrix} \sqrt{\frac{\beta_2}{\beta_1}}(\cos(\Delta\mu) + \alpha_1 \sin(\Delta\mu)) & \sqrt{\beta_1\beta_2}\sin(\Delta\mu) \\ -\frac{(1+\alpha_1\alpha_2)\sin(\Delta\mu) + (\alpha_2 - \alpha_1)\cos(\Delta\mu)}{\sqrt{\beta_1\beta_2}} & \sqrt{\frac{\beta_1}{\beta_2}}(\cos(\Delta\mu) - \alpha_2 \sin(\Delta\mu)) \end{pmatrix}$$

So:

$$\begin{pmatrix} y_2 \\ y_2' \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} y_1 \\ y_1' \end{pmatrix} \rightarrow \begin{cases} y_2 = M_{11} y_1 + M \\ y_2' = M_{21} y_1 + M \end{cases}$$

We want to translate the particles from the begining of the crab cavity to the end. We can phase advance and beta functions is negligeable, so that $M_{11} = 1$. We then have:

$$y_2 = y_1 + M_{12} y_1'$$

where we can replace y_1' by the kick formula:

$$y_2 = y_1 + M_{12} \frac{qV \sin\left(\phi_s + \frac{\omega z}{c}\right)}{E}$$

We know that the voltage has to be chosen in order to compensate half the crossing angle θ. The slope is:

$$\tan(\theta) = \frac{\Delta y}{\Delta s} \approx \frac{dy}{ds} \quad \rightarrow \quad \tan(\theta) = \frac{d\left(y_1 + M_{12}\frac{qV \sin\left(\phi_s + \frac{\omega z}{c}\right)}{E}\right)}{ds}$$

$z = s - s_0$ where s_0 is the position in the center of the bunch. Assuming small angles the expression can be simplified into:

$$\tan(\theta) = \frac{M_{12} qV\omega}{cE} \quad \Rightarrow \quad V = \frac{cE \tan(\theta)}{q\omega M_{12}} = \frac{cE\tan(\theta)}{q\omega\sqrt{\beta_1\beta_2}\sin(\Delta\mu) n_{cc}}$$

The voltage to close the bump would then be:

$$V_2 = -M_{22} V$$

where M_{22} denotes the $(2, 2)$ element of the optical transfer matrix from the first CC to the second one downstream.

$$M_{22} = \sqrt{\frac{\beta_1}{\beta_2}}(\cos(\Delta\mu) - \alpha_2 \sin(\Delta\mu)) \approx \sqrt{\frac{\beta_1}{\beta_2}}(\cos(\Delta\mu))$$

where the subindex 1 denotes *upstream* and 2 denotes *downstream*. The phase advance between the CCs and the IP is optimized to be $\Delta\mu = \frac{\pi}{2}$.

Derivation of the displacement

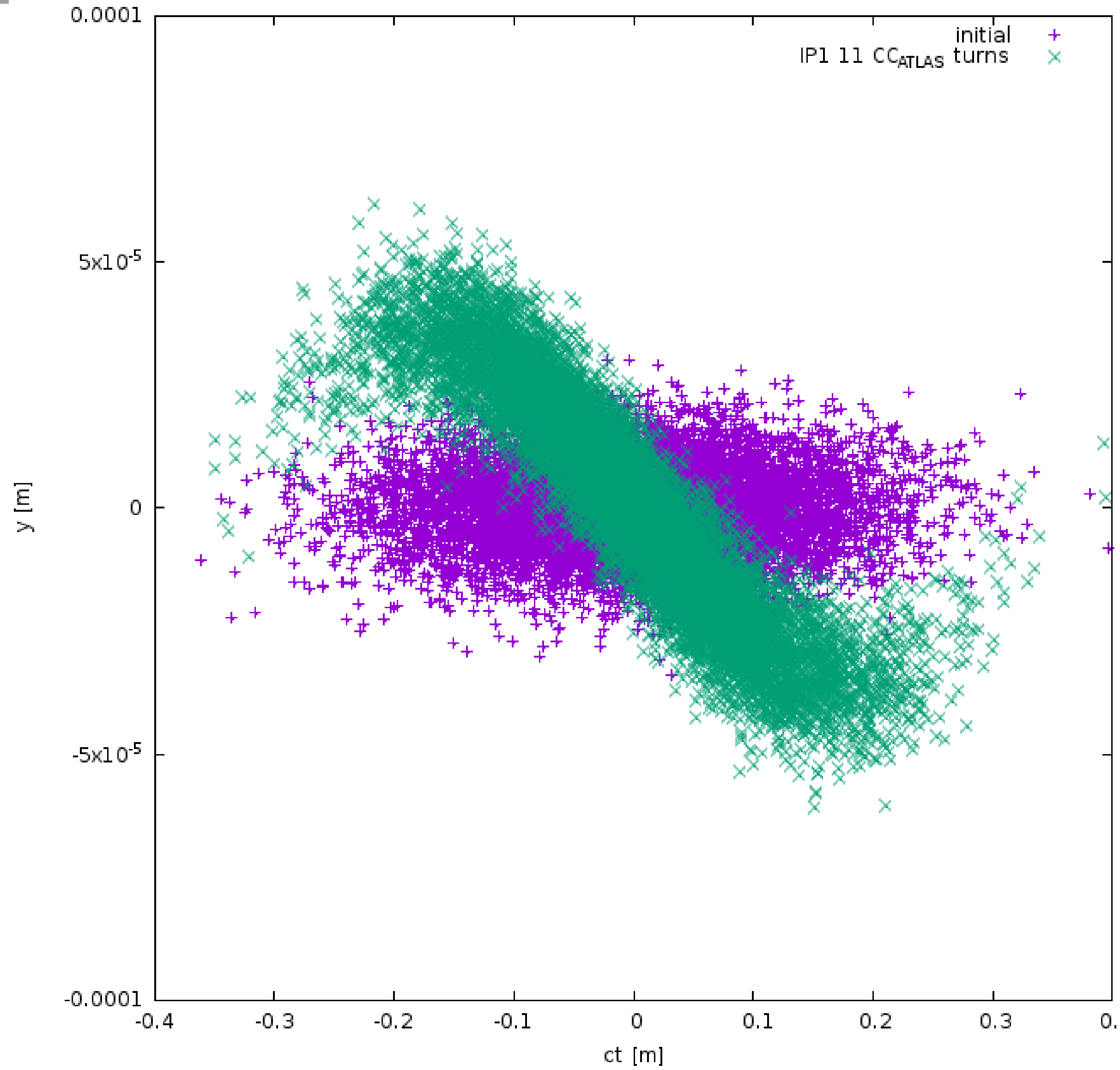
Coming back to the equation:

$$y_2 = y_1 + M_{12} \frac{qV \sin\left(\phi_s + \frac{\omega z}{c}\right)}{E}$$

Andrea Santamaría García

Thin CC Kick

Vertical crabbing @ IP1 (ATLAS)



Closed Bump

Bunch at TCP after a full 'CC' turn

'Pre tracked'

IP1 -> First ATLAS CC

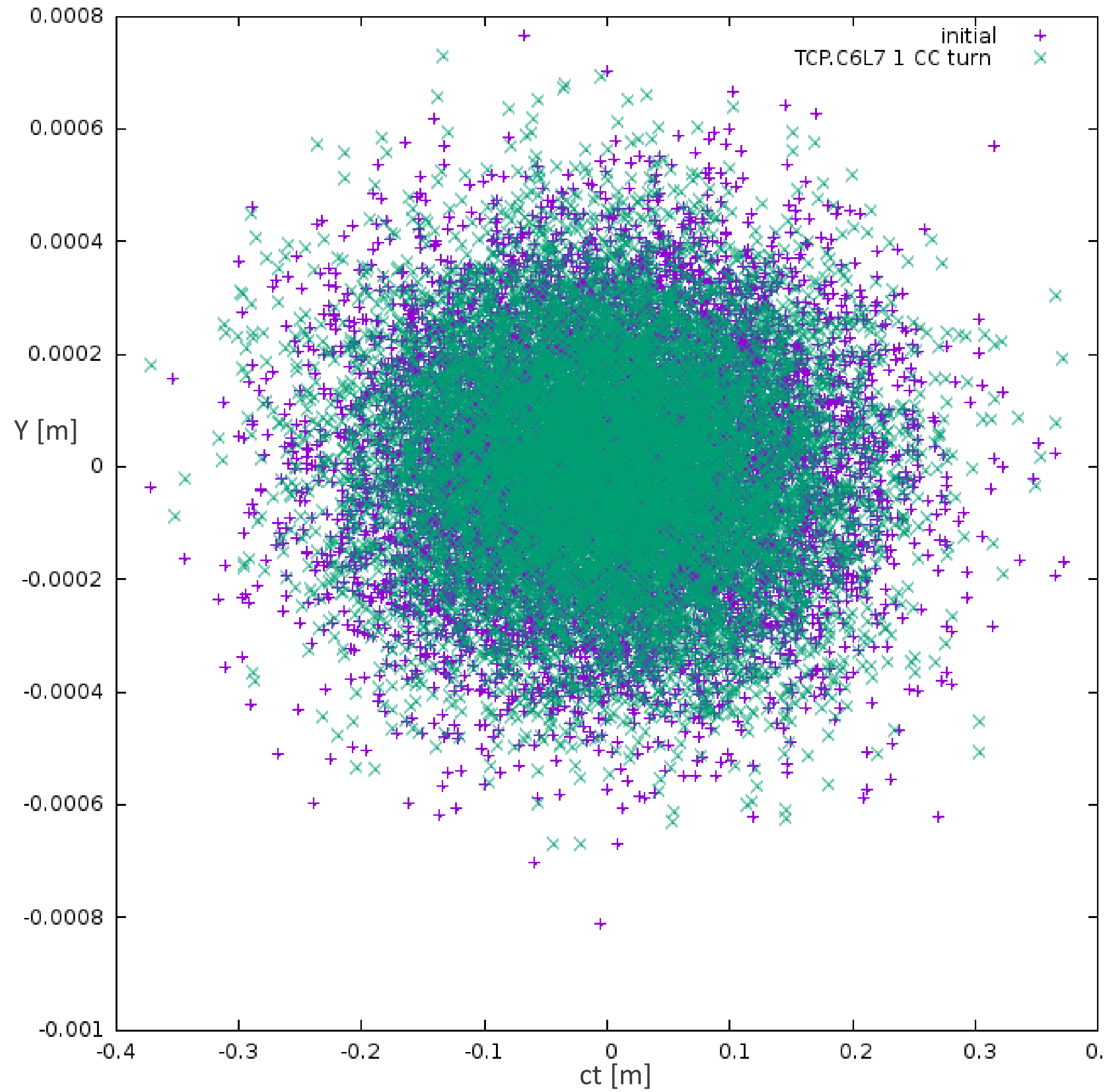
'Tracked + CCF Process'

First ATLAS CC -> 1 turn

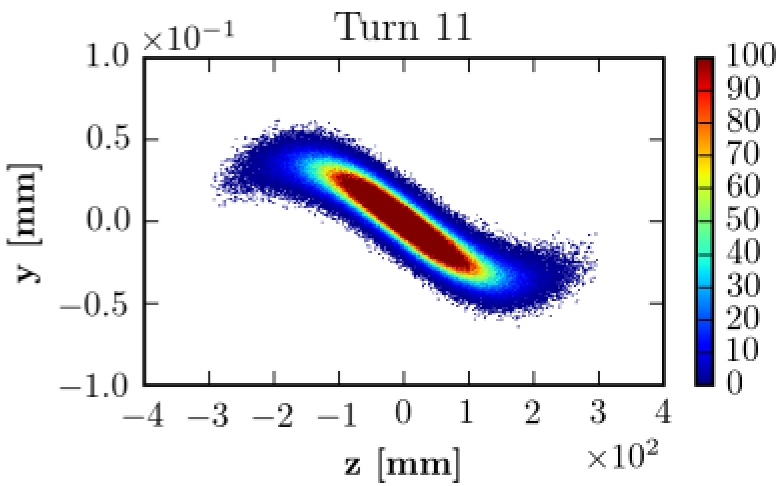
'Post tracked'

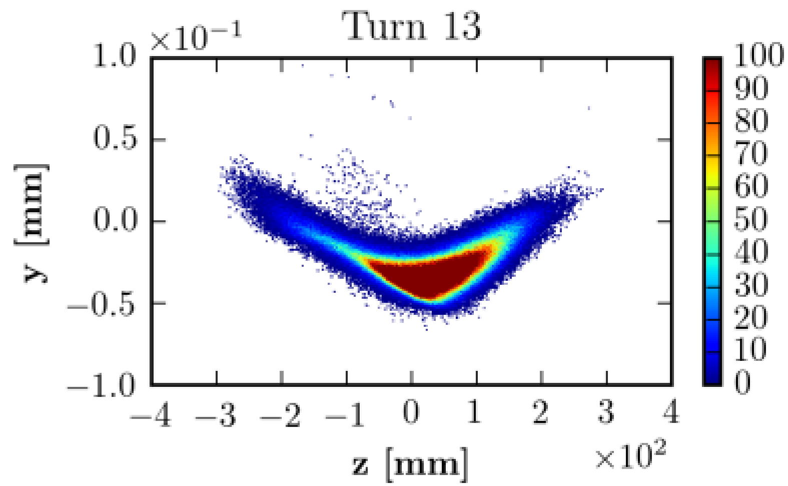
First ATLAS CC -> IP1

Holds for many turns

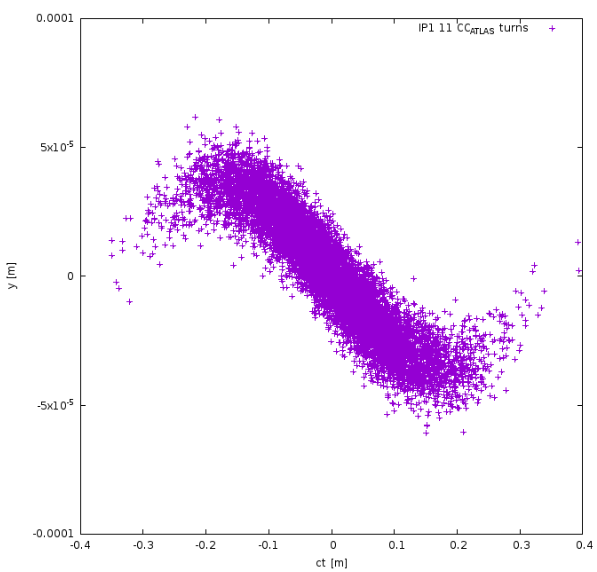


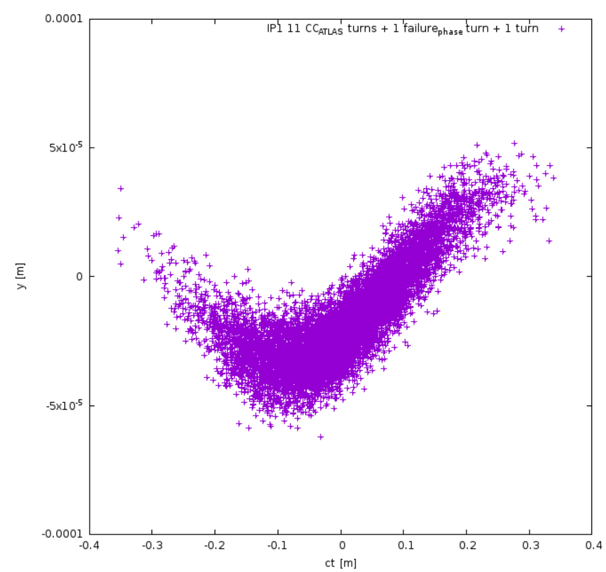
4 CC 90° Phase Failure





A. Santamaría
(Wednesday)





MERLIN
(Thursday)

FUTURE

Documentation

- Sourceforge (not up to date)
- GitHub (in near future)
- Current git repository is private

- HR merlin site: https://sites.google.com/site/haroonrafiquemerlin/

- HR HEL site: https://sites.google.com/site/hollowelens/home

- HR thesis – early 2016

Future Work

Run **side-by-side with SixTrack** for HL LHC (J. Wagner @CERN)

Use of **CC failure** model (A. Santamaría @ CERN)

HEL integration study (A. Rossi @ CERN)?

Support of **MERLIN use @ CERN** (A. Valloni + many more)

CC failure + HEL + Loss Maps?

S. Tygier – **HL squeeze loss study**

Always welcome new users / new applications

H. Rafique **PhD Thesis** (Early 2016)

All of the above + MERLIN manual

Future HEL Work

1. MERLIN vs SixTrack for identical bunches, various operation modes (Poincare Sections)
2. Investigation of optimal AC mode parameters in HL v1.2
3. Investigation of optimal HEL position in HL v1.2
4. Cleaning enhancement with more realistic TCP setting (use 6.2 sigma now, possibly 6 or 5.7 sigma in future) for all modes
5. Cleaning enhancement with scattering (for all modes) - currently use TCP as a black absorber
6. Cleaning enhancement with a full collimation scheme (for all modes)
7. Cleaning enhancement for all above with a more realistic bunch (for all modes)
8. Crab Cavity failure model
9. Loss map with CC failure
10. Loss map with HEL and CC failure (with HEL halo depletion post, pre, and both post & pre CC failure)

Acknowledgements

J. Molson & M. Serluca	– MERLIN development
R. Bruce & S. Redaelli	– Collimation
A. Santamaría	– CC failure
D. Mirarchi & J. Wagner	– HEL
A. Valloni	– Sanity check

Questions?