Evolution de la source X Compton Inverse d'ELSA et simulation de son compresseur double alpha (CEA DAM, France)

Présentation flash doctorant

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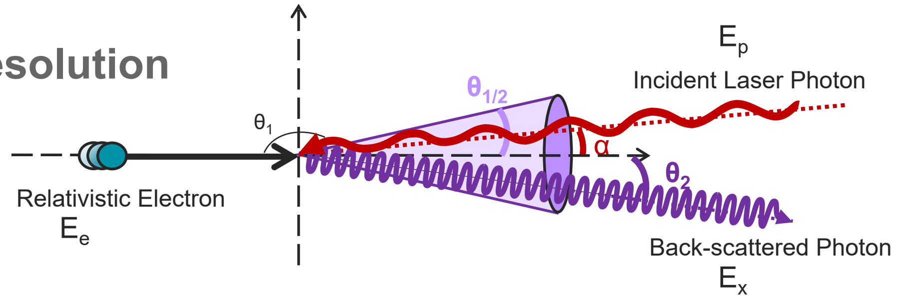
1. Increasing the yield of an ICS X-ray Source

Increasing the yield of an ICS X-ray Source

Inverse Compton X-ray Source

Inverse Compton X-ray Source : **(laser + electron bunch → X-ray)**

- **Monochromatic and directional radiation sources with high temporal resolution**
- **Compton scattering cross section is very small**
  → need lot of efforts to increase yield



ELSA ICS source :

- **Compact X-ray source for diagnostic characterization (for Laser Mega Joule)**
- **versatile : single shot (primary use) – recurrent**
  - 532 or 1064 nm laser ($E_p = 2{,}3$ or $1{,}1\ eV$) + relativistic electrons ($E_e = 18 - 30\ MeV$)

→ X-ray photons $\mathbf{E_X = 12 - 40\ keV}$

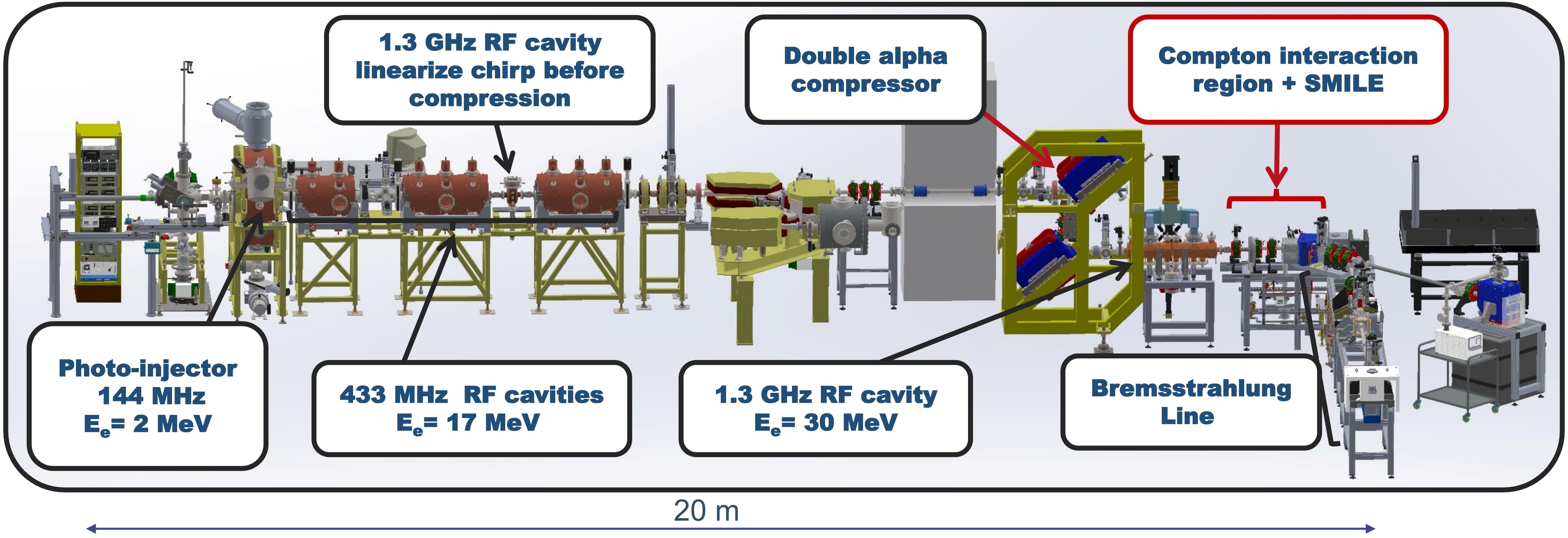
$$E_X = \frac{4\gamma^2 E_p}{1 + \gamma^2\theta_2^2 + \frac{\alpha^2}{4}}$$

$$E_X(\theta_2 = 0) = 4\gamma^2 E_p$$

$$\theta_{1/2} = \frac{1}{\gamma}$$

ELSA Accelerator (CEA DAM, France)

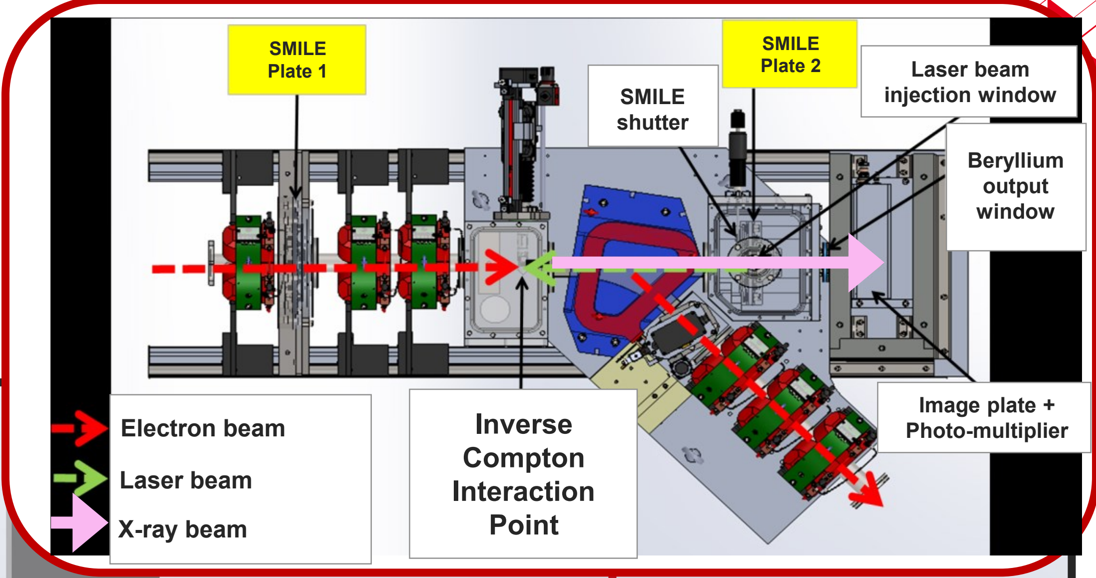
3D view

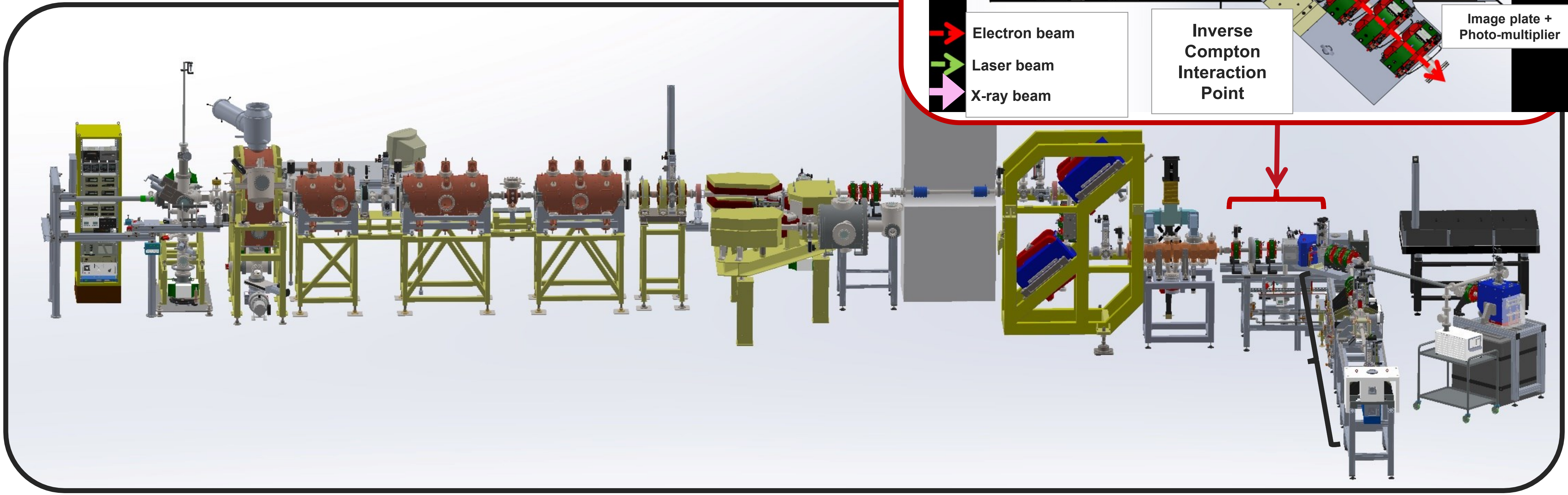


Typical bunch charge : 0.1 – 3 nC
Bunch duration : 15 – 100 ps
1 – 10000 bunches per train (1 – 5 Hz)
Emittance : 2 – 30 µm

ELSA Accelerator (CEA DAM, France)

3D view





Increasing the yield of an ICS X-ray Source

	Pitfalls :	Solutions :
Interaction area	- Beams alignment - Mechanical stability	Re-design the interaction area (SMILE 2)
Laser	- Efficiency of frequency doubling	Using the laser at 1064nm instead of 532nm with a remote alignment method
Laser	- Laser Induced Damage Threshold (LIDT) - Non-linear effects	Temporal stretching by CPA (Chirped Pulse Amplification)
Electrons	- Space charge effects	Twiss parameters and charge that maximize X-ray yield
Electrons	- Bunch duration	Using a decelerating 1.3 GHz cavity to achieve linear chirp before compression
Electrons +	- Bunch energy - Train duration	Upgrading the 1.3 GHz cavity and Klystron system

Increasing the yield of an ICS X-ray Source

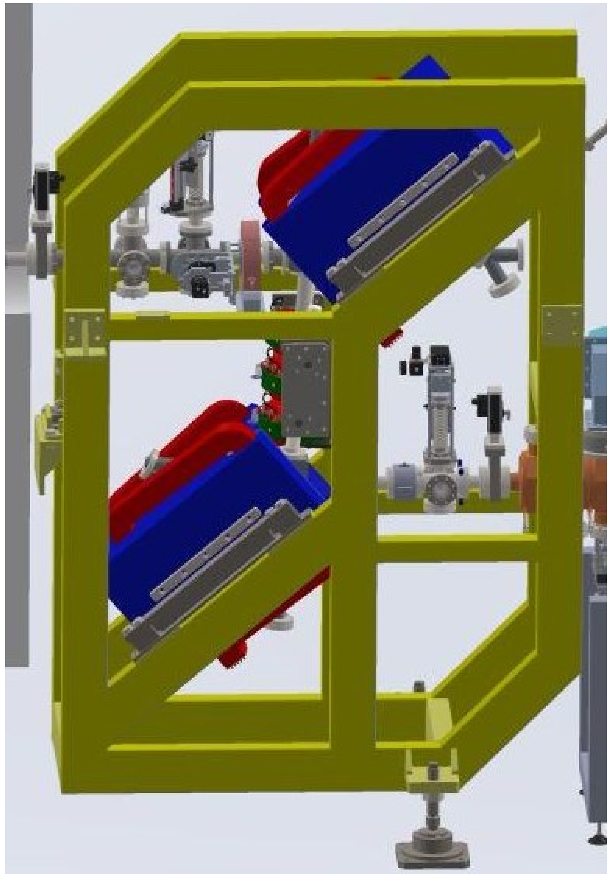
Solutions :

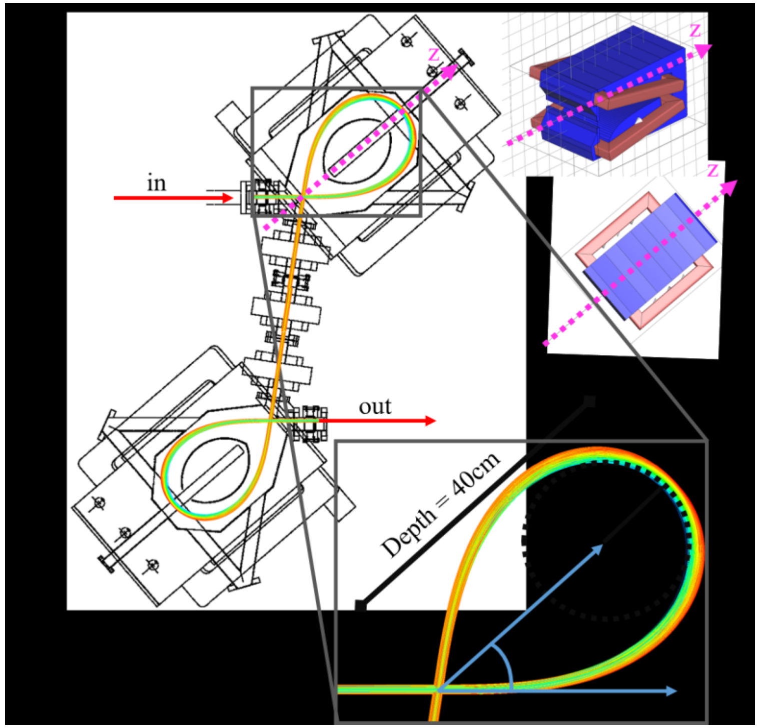
Twiss parameters and charge that maximize X-ray yield

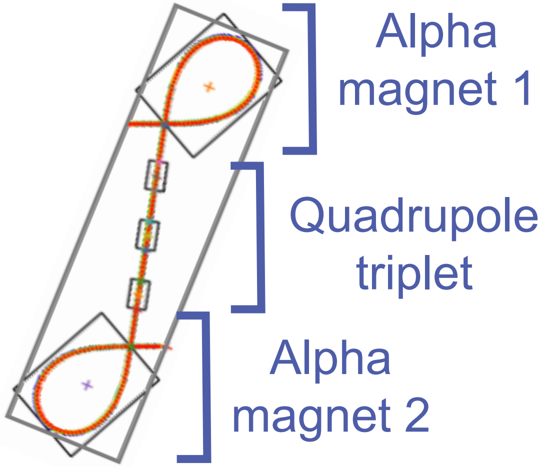
2. Simulating electron beam in alpha magnet and frame change

Simulating electron beam in alpha magnet compressor

Double alpha magnet compressor



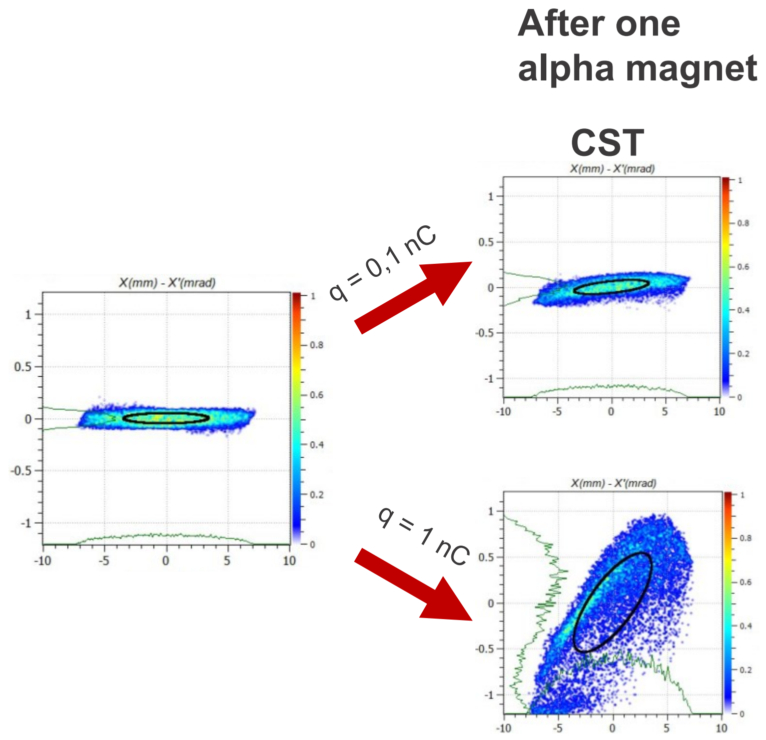




Simulating electron beam in alpha magnet compressor

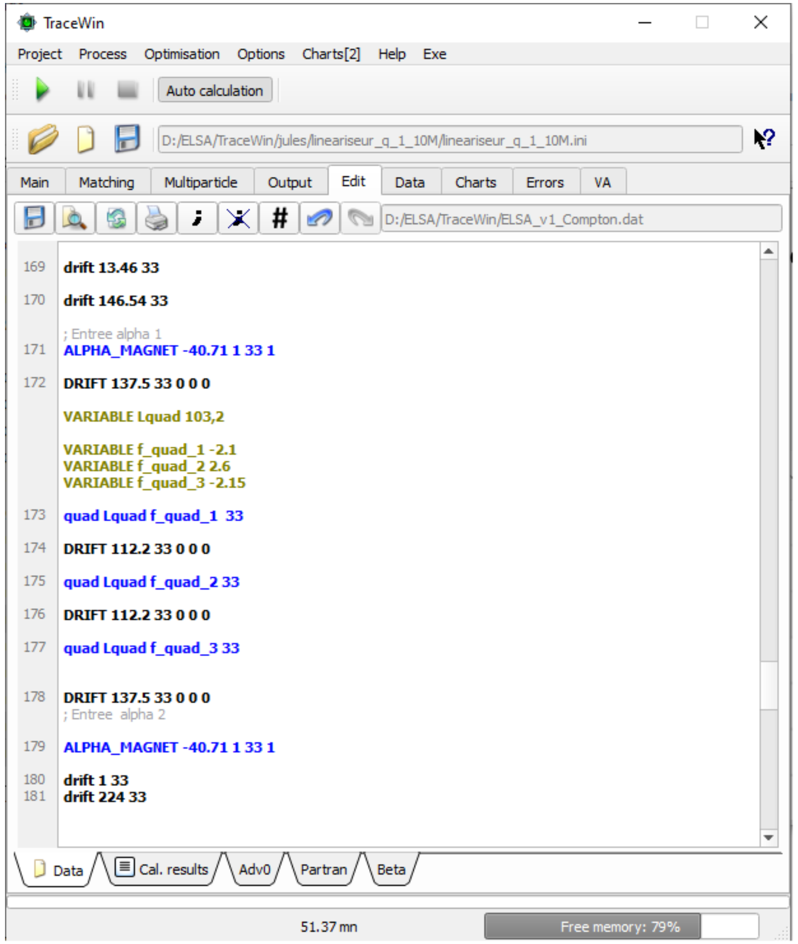
Double alpha magnet compressor

- The ICS Source is located after a double-alpha magnet compressor
- Good compression with linearizer
- IMPORTANT EMITTANCE GROWTH WITHIN THE ALPHA MAGNETS
- Simulation to optimize beam transport
- Is it possible to reach desired flux with a double alpha magnets ?



Simulating electron beam in alpha magnet compressor

Using transfer matrix in TraceWin



The final matrix of a fraction of a alpha magnet (on which, X_s and θ_s are kept almost constant) :

$$\begin{pmatrix} \cos\theta_0+(1-\cos\theta_0)\cdot\frac{\rho_0\cdot\sin\theta_s}{X_s} & \rho_0\cdot\sin\theta_s & 0 & 0 & 0 & \rho_0\cdot(1-\cos\theta_0) \\ -\frac{\sin\theta_0}{\rho_0}\cdot\left(1-\frac{\rho_0\cdot\sin\theta_s}{X_s}\right) & \cos\theta_0 & 0 & 0 & 0 & \sin\theta_0 \\ 0 & 0 & \cos\left(\sqrt{K}\rho_0\theta_0\right) & \frac{\sin\left(\sqrt{K}\rho_0\theta_0\right)}{\sqrt{K}} & 0 & 0 \\ 0 & 0 & -\sqrt{K}\cdot\sin\left(\sqrt{K}\rho_0\theta_0\right) & \cos\left(\sqrt{K}\rho_0\theta_0\right) & 0 & 0 \\ K_\varphi\cdot\left(\sin\theta_0+(\theta_0-\sin\theta_0)\cdot\frac{\rho_0\sin\theta_s}{X_s}\right) & K_\varphi\cdot\rho_0\cdot(1-\cos\theta_0) & 0 & 0 & 1 & K_\varphi\cdot\rho_0\cdot(\theta_0-\sin\theta_0) \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

With: $K=\frac{k\cdot\sin\theta_s}{X_s}$,

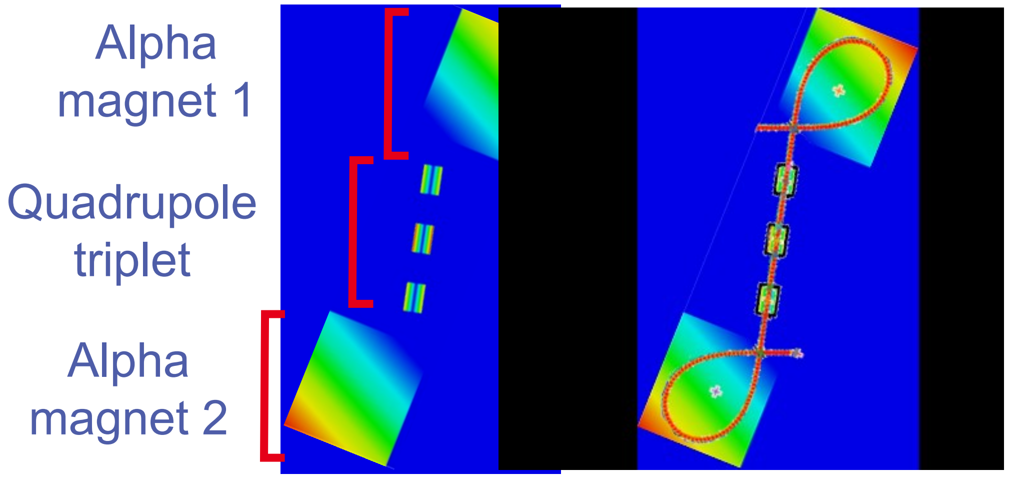
And: $K_\varphi=\frac{2\pi\cdot f_{RF}}{\beta_0 c}$.

The matrix of the full element is a product of all matrixes for varying X_s and θ_s.

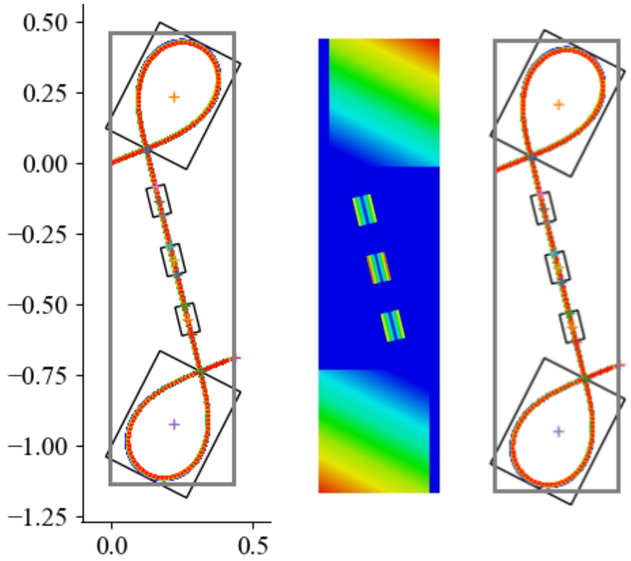
- **Experiments show larger emittance growth than TraceWin simulations → use CST PS**

Simulating electron beam in alpha magnet compressor

Using fields maps in CST



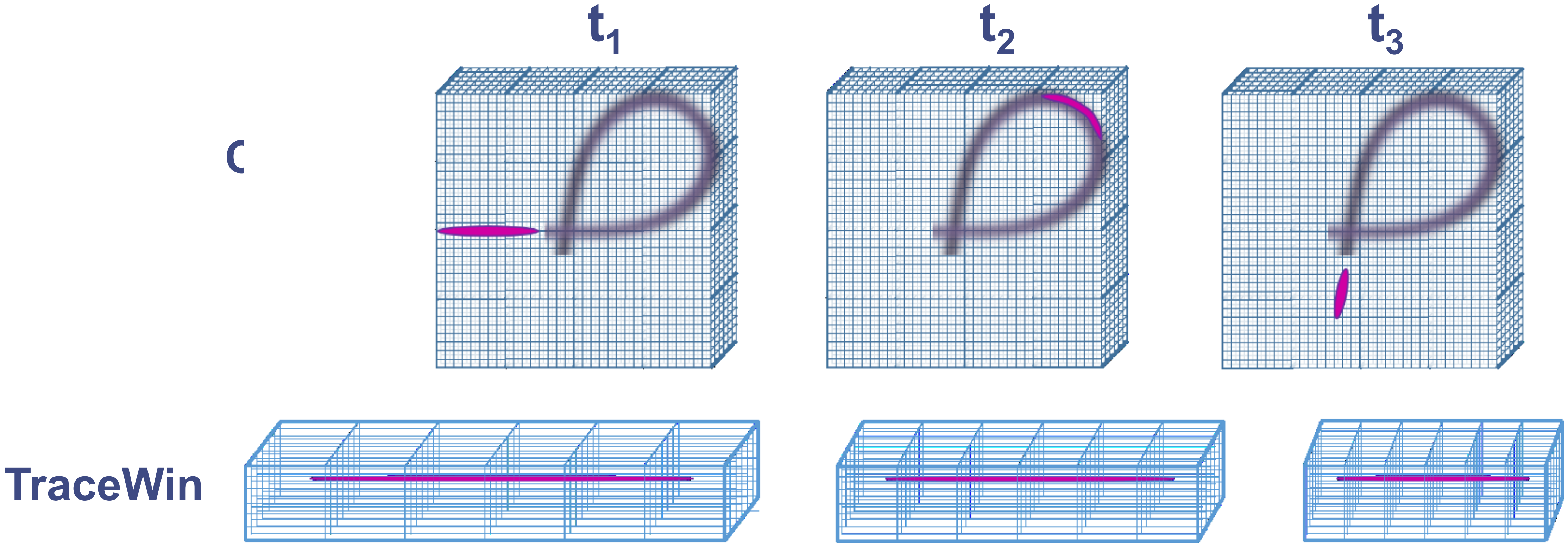
22° rotation to minimize number of meshcells



Simulating electron beam in alpha magnet compressor

Mesh in CST vs TraceWin

3D mesh cells for PIC algorithm and space charge computation



Simulating electron beam in alpha magnet compressor

PIC in CST vs TraceWin

Calcul PIC électrostatique

Bunch frame:

$v << c \Rightarrow \vec{j}$ negligible $\Rightarrow$ ***electrostatic assumption***

- charge density ρ projected on meshgrid
- V(ρ) scalar potential (Poisson's equation)
- E(V) electric field
- Lorentz boost (change of frame)★
- F=q(E + V^B) Lorentz force, update velocities
- update positions

TraceWin

CST PS

Calcul PIC électrodynamique

Lab. Frame or important transverse velocities :

v ~~<<~~ $c \Rightarrow$ ~~$\vec{j}$ negligible~~ $\Rightarrow$ ~~*electrostatic assumption*~~

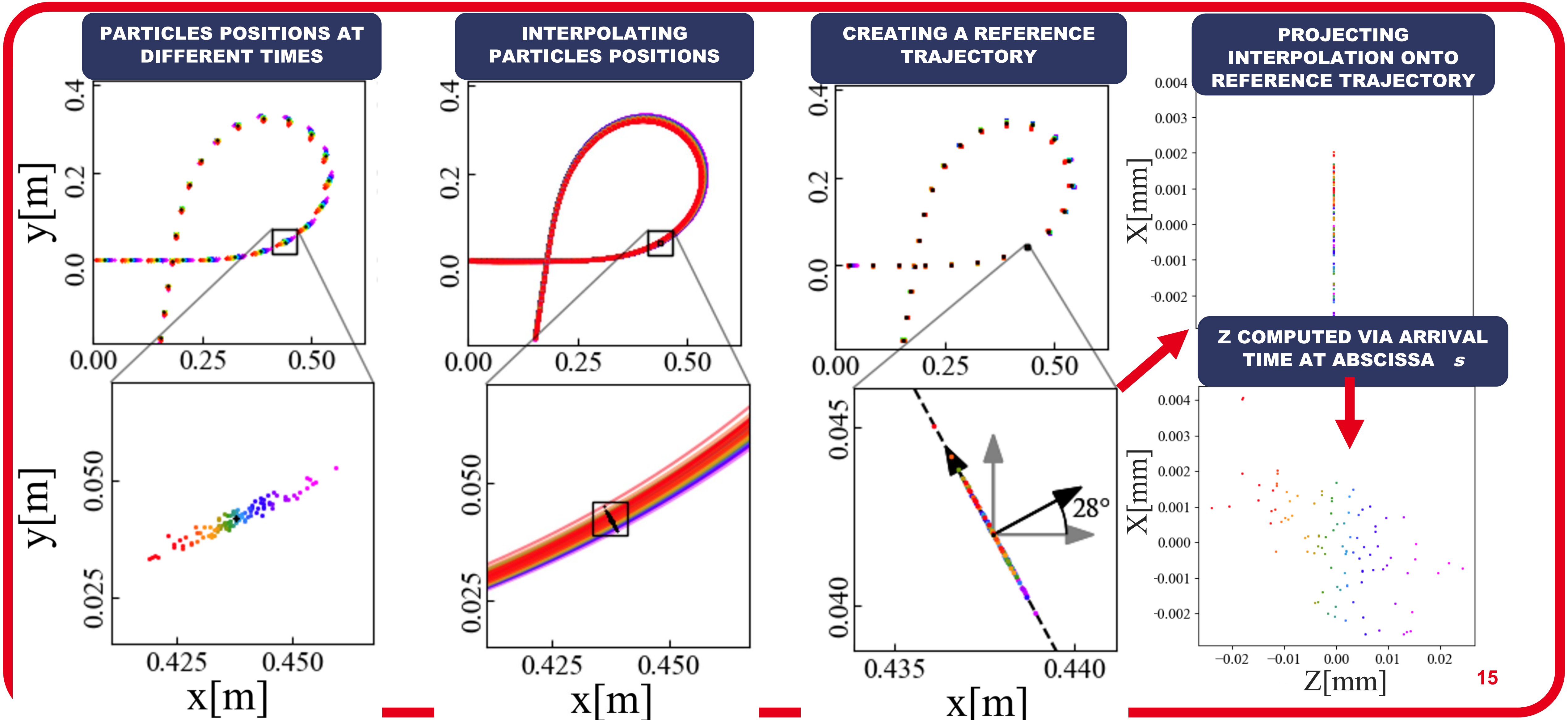
- Charge density ρ and current density $\vec{J}$ projected on meshgrid
- V(ρ) scalar potential (Poisson's equation) and $\vec{A}$ vectoril potential (Ampere's equation)
- E(V) electric field and B($\vec{A}$) magnetic field
- Lorentz boost (change of frame)★
- F=q(E + V^B) Lorentz force, update velocities
- update positions

★
$$\begin{cases} E'_x = E_x \cdot \\ E'_y = \gamma(E_y - \beta c B_z) \cdot \\ E'_z = \gamma(E_z + \beta c B_y) \cdot \\ B'_x = B_x \\ B'_y = \gamma(B_y + \frac{\beta}{c} E_z) \\ B'_z = \gamma(B_z - \frac{\beta}{c} E_y) \end{cases}$$

E_{lab} and B_{labo} from E_{bunch} and B_{bunch}

Frame change

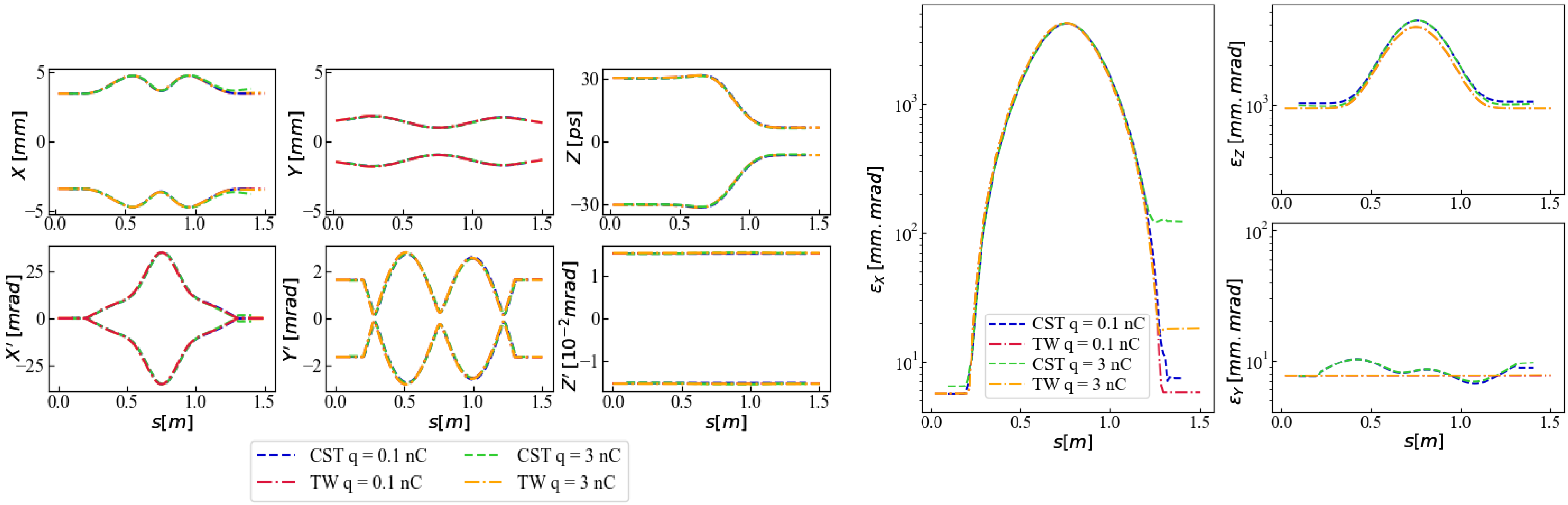
Key steps from laboratory frame to reference frame



Frame change

Frame change is necessary to obtain proper phase space

- Good agreement between CST and TraceWin at low charge (0,1 nC) validate the methods
- Larger emittance growth at high charge with CST



Results for one alpha magnet, see poster for the whole compressor !

Other codes to consider

RF-Track (CERN)
- Electrostatic or electrodynamic
- Transfer Matrix or field maps
- Can simulate Compton interaction

WARP-X (LANL)
- Electrostatic or electrodynamic
- Transfer Matrix or field maps
- Massively parallel

GPT (commercial)
- Electrostatic for PIC computation
- Particle-particle module available (PP)

OPAL (PSI)
- Electrostatic but computation within reference frame after energy bining (thus lower dispersion)
- Transfer Matrix or field maps
- Massively parallel

COMSOL (commercial)
- Particle-particle module available (PP)

ASTRA (DESY)
- Electrostatic
- Transfer Matrix or field maps
- Famous

3. Conclusion

Conclusion - Prospect

Beam transport simulation :

- Electrostatic hypotheses seems inapropriate
- Full electrodynamic in laboratory frame is time consuming

Perspectives :

- Using RF-Track
- Compton source experiments on ELSA → Compare/validate simulations

Other means to increase the yield :

- new 1,3 GHz chirp linearizer,
- new CPA system,
- new SMILE device,
- Laser at 532 instead

THANK YOU

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