The CEA-Saclay codes

R. Duperrier, N. Pichoff, D. Uriot
CEA-France

Goal

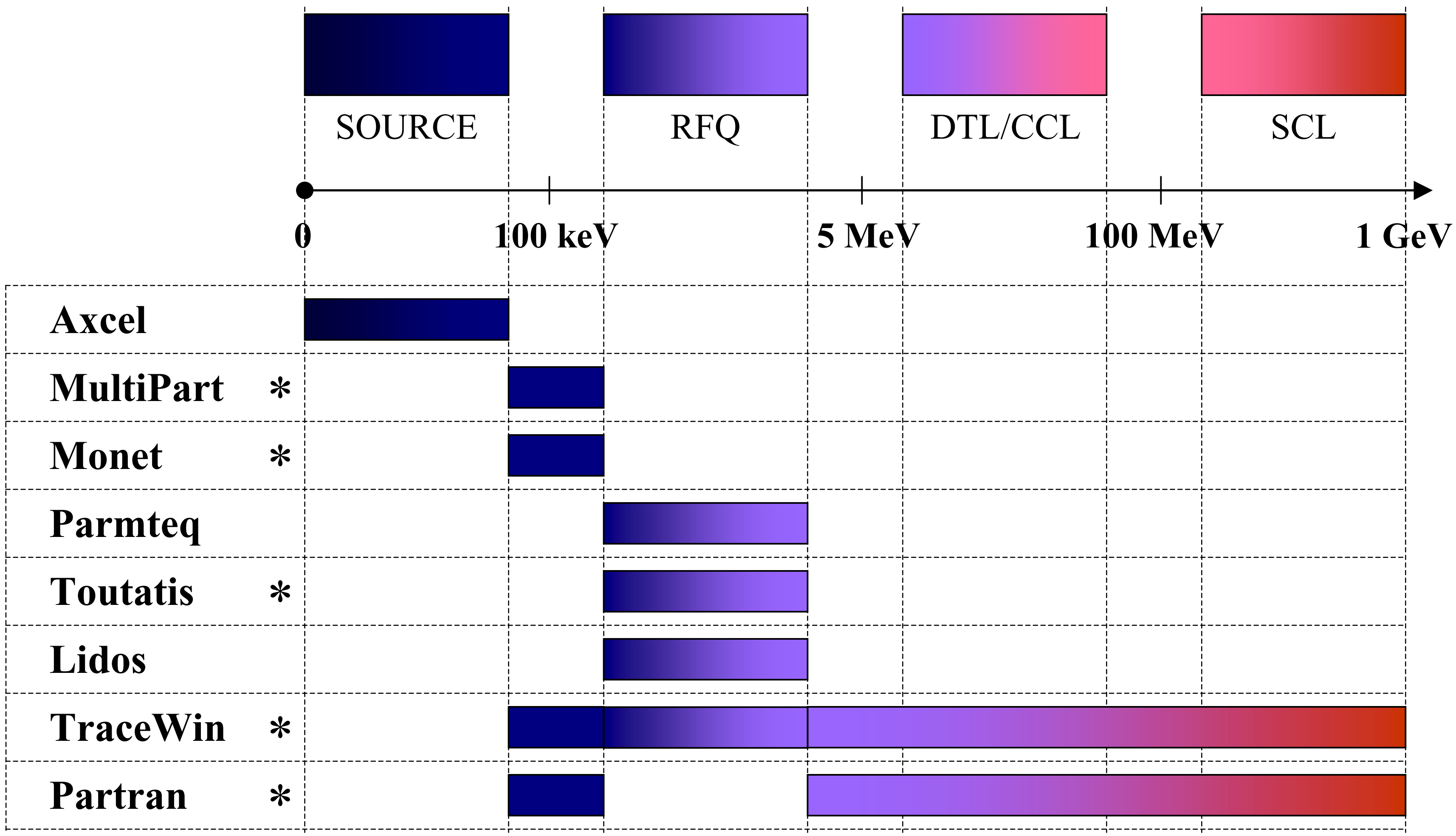
• A set of codes has been written last years at Saclay to be able to transport a beam from the beginning to the end of a high power proton linac.

• Linac design, matching and multiparticle simulations are the main purpose of these codes.

• These codes have been designed to run on mono-processor computers (mainly PC).

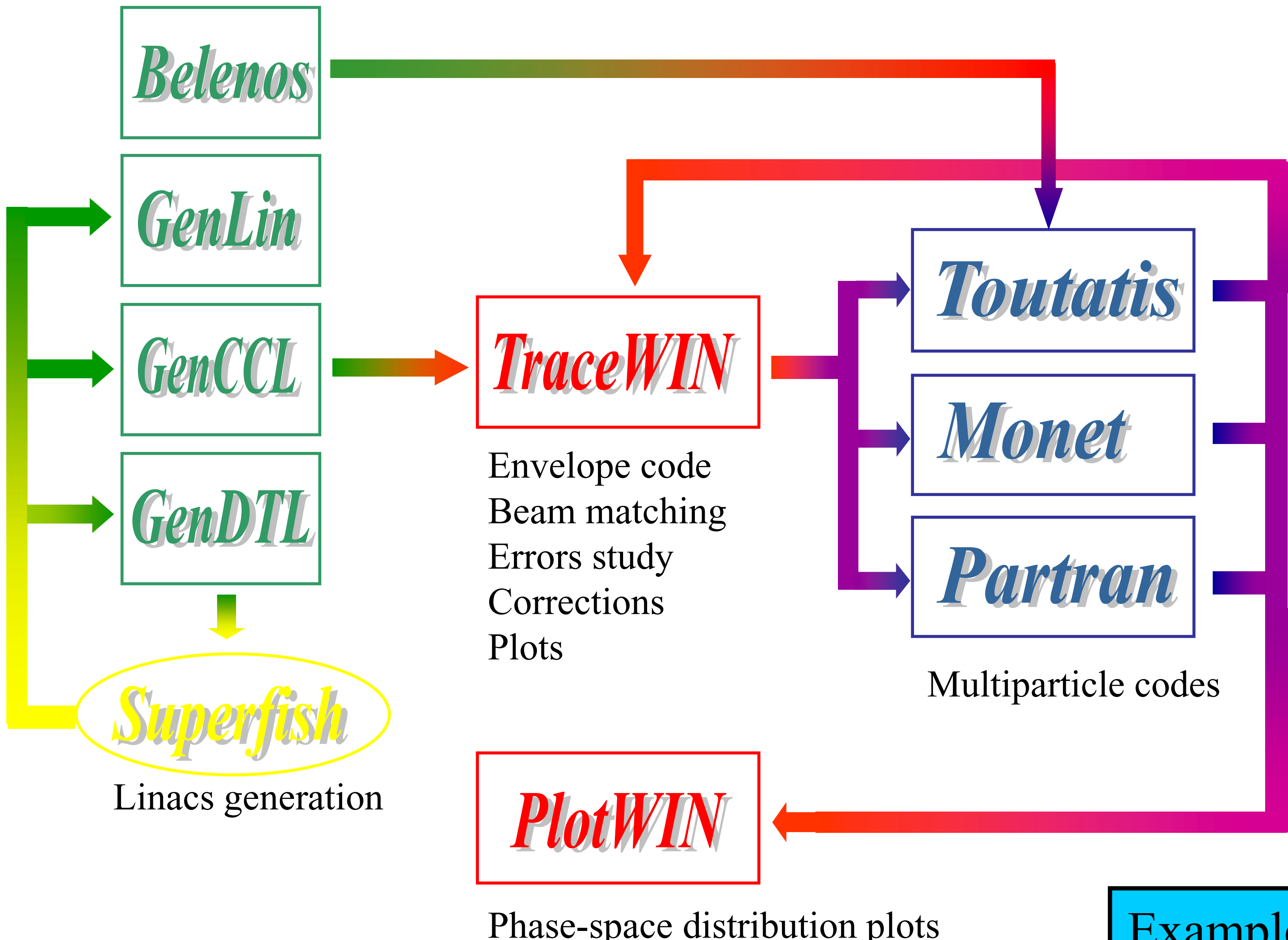
• Time consuming calculations like linac error studies can be done in parallel with many PCs through the local net.

Beam dynamics codes used in CEA



* codes written in CEA

Codes organisation



Example

Stupido !!!

You’ve missed the button

I’m a stupido

Belenos: RFQ design

Input

Frequency, reference particle, initial and final energy, beam current, emittance

- Length of Bunching section (in cells), Length of the cavity
- Aperture, maximum modulation, maximum peak field
- Transition between bunching and accelerating section (synchronous phase ramp)
- Voltage, pole curvature, Minimum synchronous phase

Work

Compute voltage and aperture to compensate bunching without peak field enhancement using R-Z beam envelopes equations

Output

Linac description in a TOUTATIS format file

GenDTL: DTL design

Input

Frequency, particle, initial and final energy, beam current, power supply distribution, field and synchronous phase laws, cell and quadrupole designs ...

Work

Cavity field and phase calculation from a synchronous particle step by step transport. Calculate cell per cell by using SUPERFISH, taking account to quadrupole design and maximum peak field wanted and phase and electric field law. Tank diameter optimisation according to the Z_sT^2

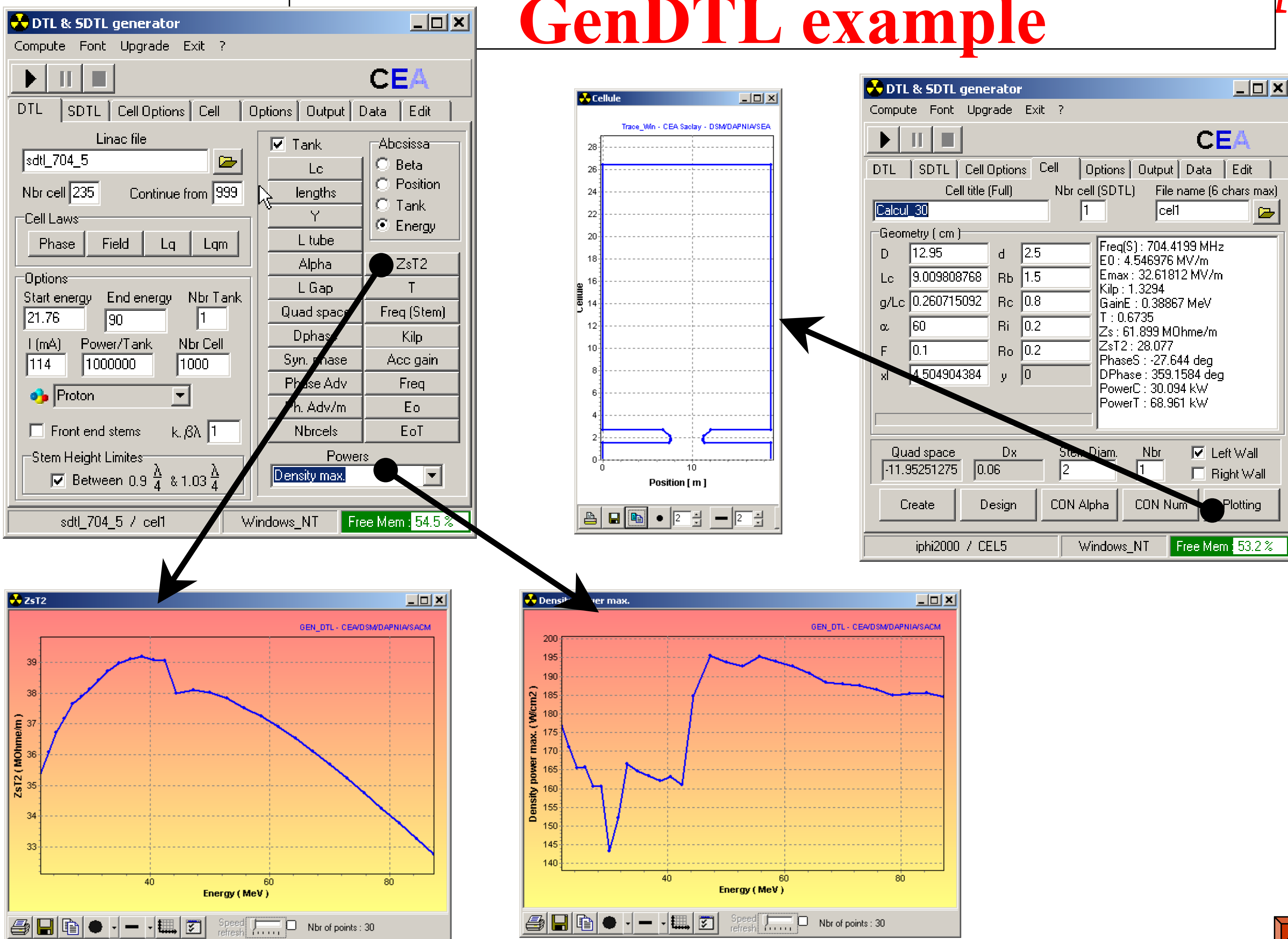
Output

A lot of chart describing the linac, power, T, field…where zoom, hardcopy, save on disk, scale change, copy-paste tools can be used.

Geometric design file of each cell.

Linac element description in a TraceWIN format file

GenDTL example



GenCCL: CCL design

Input

Frequency, particle, initial and final energy, beam current,
Medium-energy part output characteristics,

Section description (Lattice scheme, number of cell per cavity,…),
Cavity shunt impedance, maximum peak field and power,
Description of how to match it with the preceding section,

Work

Cavity field and phase calculation from a synchronous particle step by step transport.

Output

Linac description in a TraceWIN format file

GenLin: SCL design

Input

Frequency, particle, initial and final energy, beam current,
Medium-energy part output characteristics,

{ Section description (β, cells # per cav., cav. # per cryo., distances),
Cavity field description (SUPERFISH file name or model),
Maximum field and power,
Description of how to match it with the preceding section,

List of transition betas.

Work

Cavity field and phase calculation from a synchronous particle step by step transport.

Output

Linac description in a TraceWIN format file

TraceWIN: The linear code

Input

Linac element description in a TraceWIN format file,
Phase advance law,
Beam characteristics or distribution file.

Work

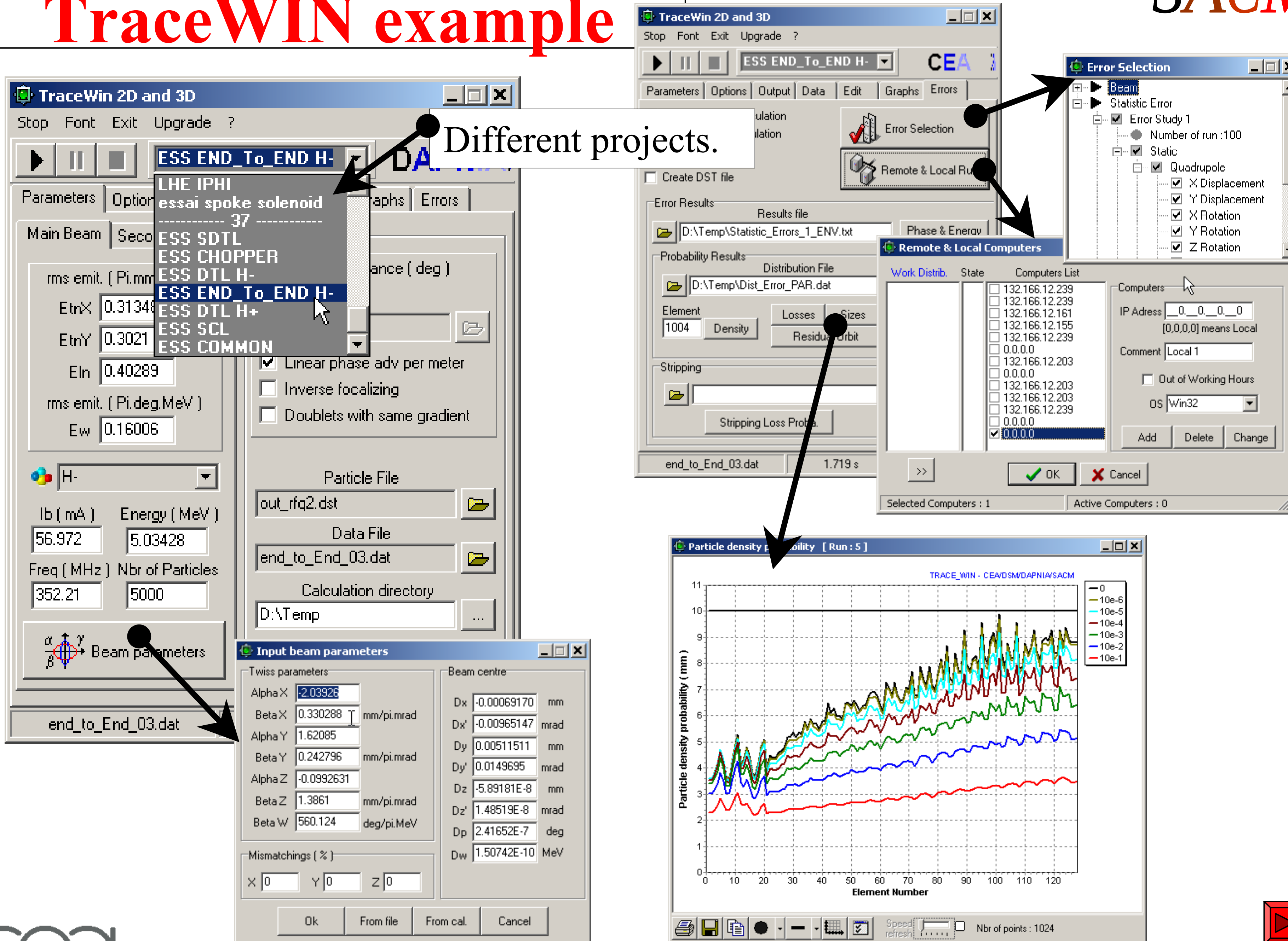
Quadrupole gradient calculation (fixed phase advance law), Input matched beam, Beam Matching (by changing quads and cavities at transitions), Envelope transport with real linear 3D space charge.
Run multiparticle codes (Partran, Monet, Toutatis), and extract all results
Error study (with linear transport or Partran) with or without correction scheme on one or several computers.

Output

A lot of plots concerning the linac (lattice length, quads gradients, cavity field, phase and power) and the beam (emittance, temperature, envelopes, tune depression, energy, phase-space distribution). Statistical results from error studies.
Zoom, hardcopy, save on disk, scale change, copy-paste tools can be used.

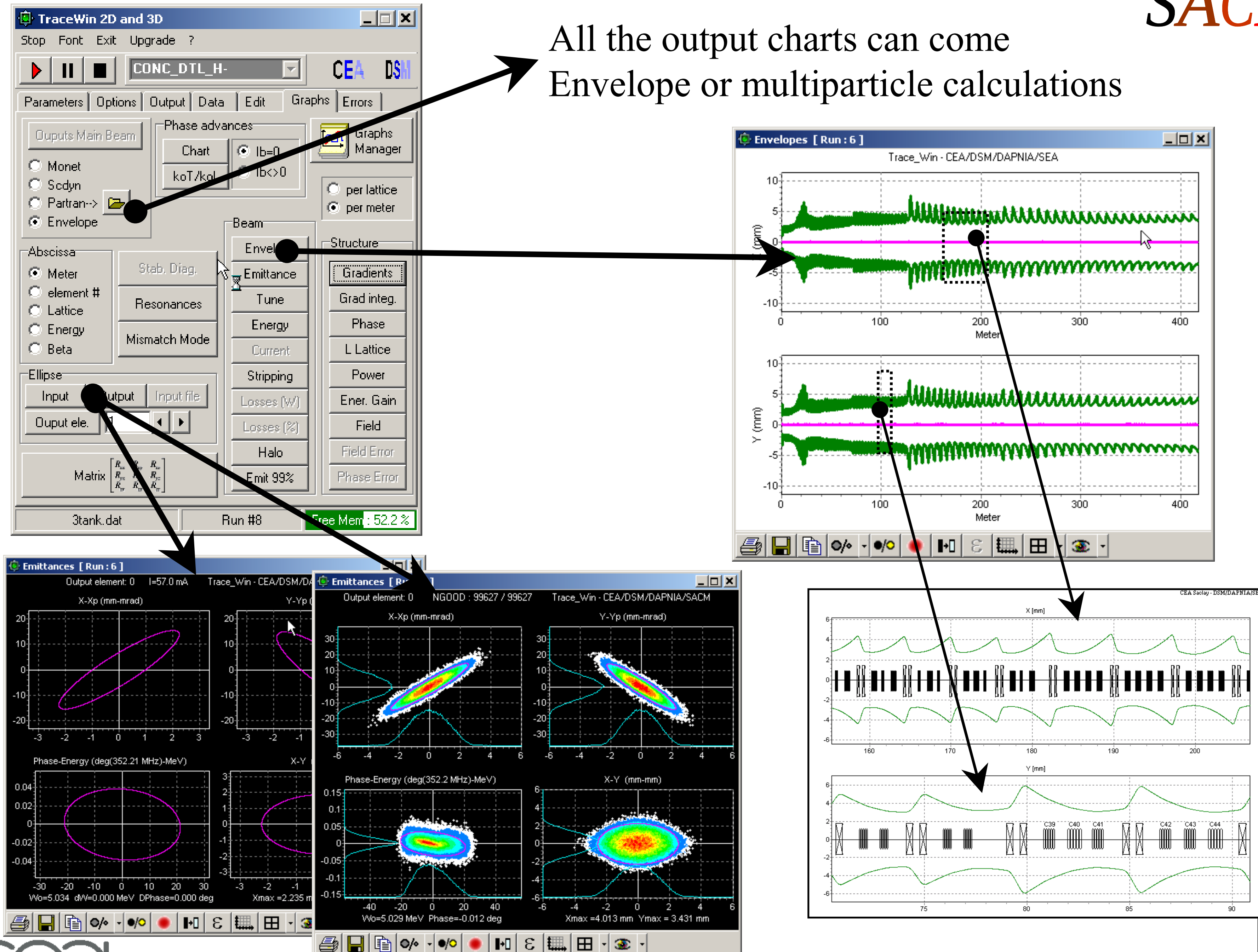
TraceWIN example

SACM



SACM

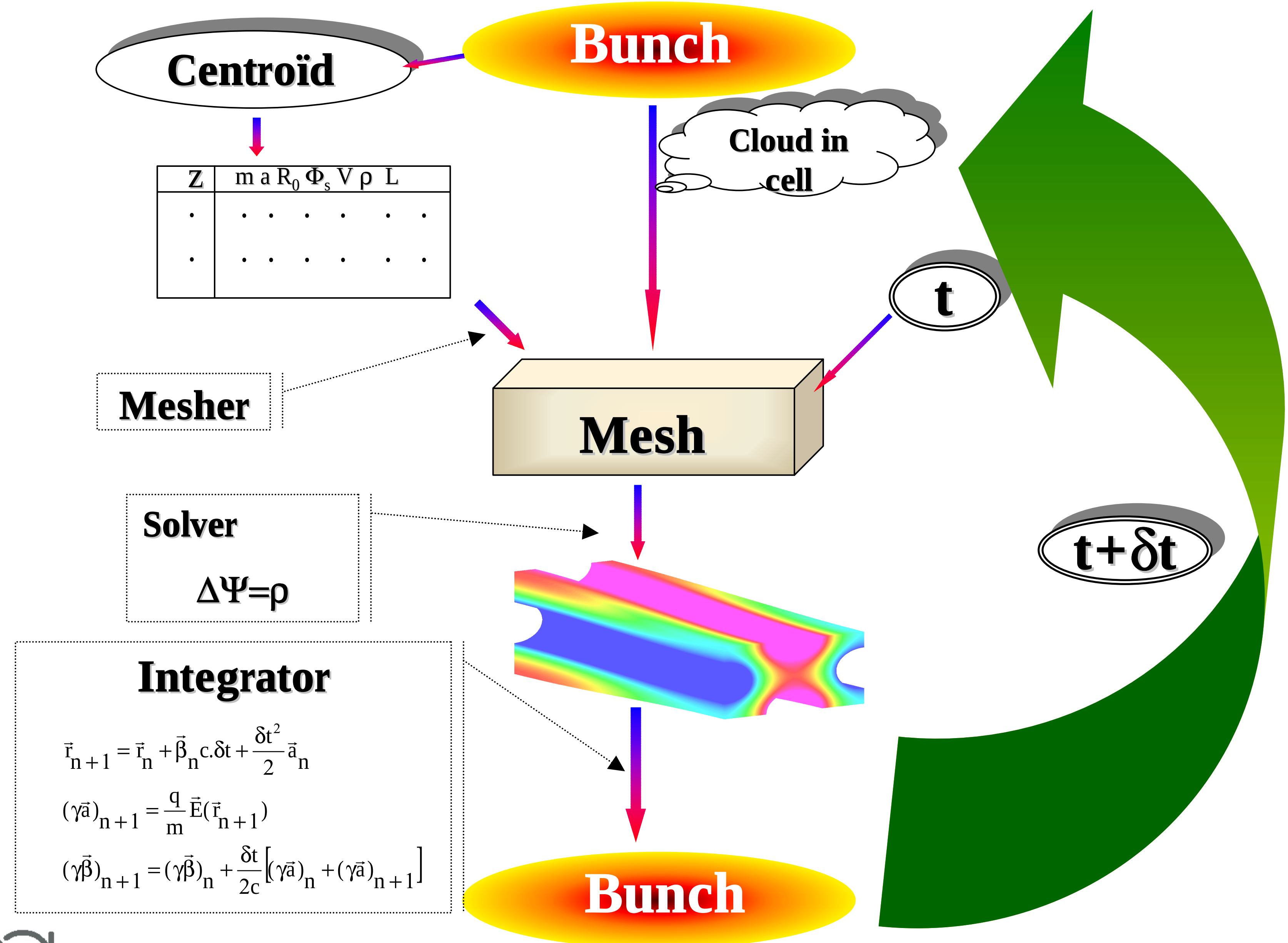
All the output charts can come Envelope or multiparticle calculations



TOUTATIS: Multiparticle transport in a RFQ

- Use Time as independent parameter for motion integration.
- Compute Space charge using a multigrid scheme
- Outputs : particles clouds or contours plots; emittances, phases advances curves, resonance diagrams, apertures, halo parameters
- Includes: space charge, image effects, real shape of the electrodes (mechanical defects, discontinuities as coupling gaps can be easily simulated)

TOUTATIS: Algorithm

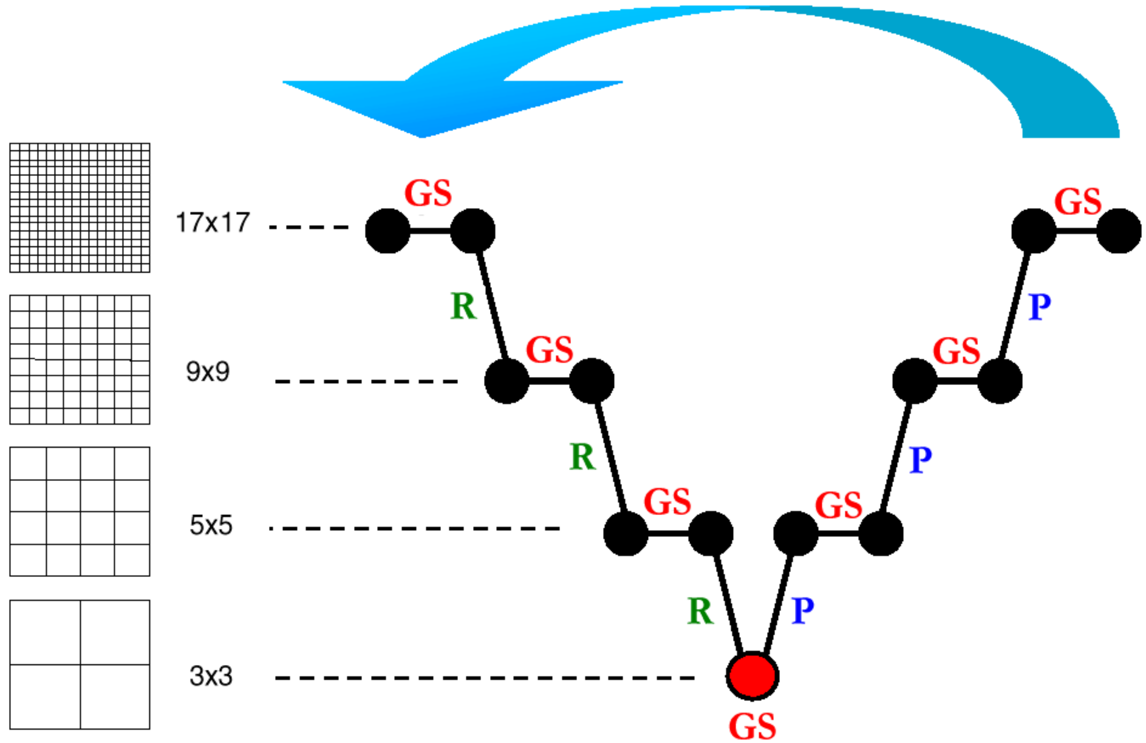


TOUTATIS: Multigrid scheme

$$\Delta\Psi = \rho$$

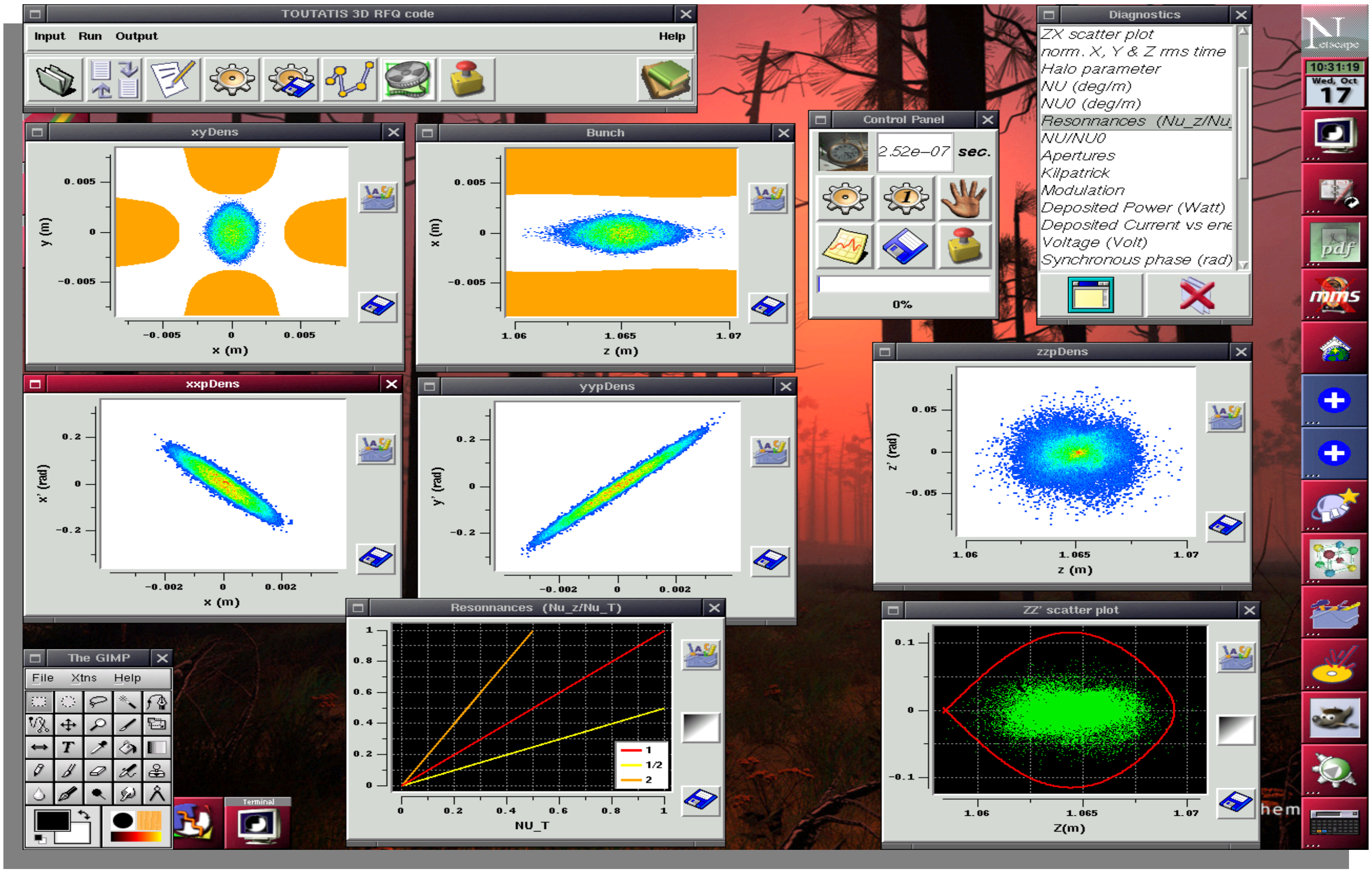
$$\tilde{\rho}^i = \Delta\Psi^i - \rho$$

$$\Psi = \Psi^i - \tilde{\Psi}^i \quad \text{with } \Delta\tilde{\Psi}^i = \tilde{\rho}^i$$

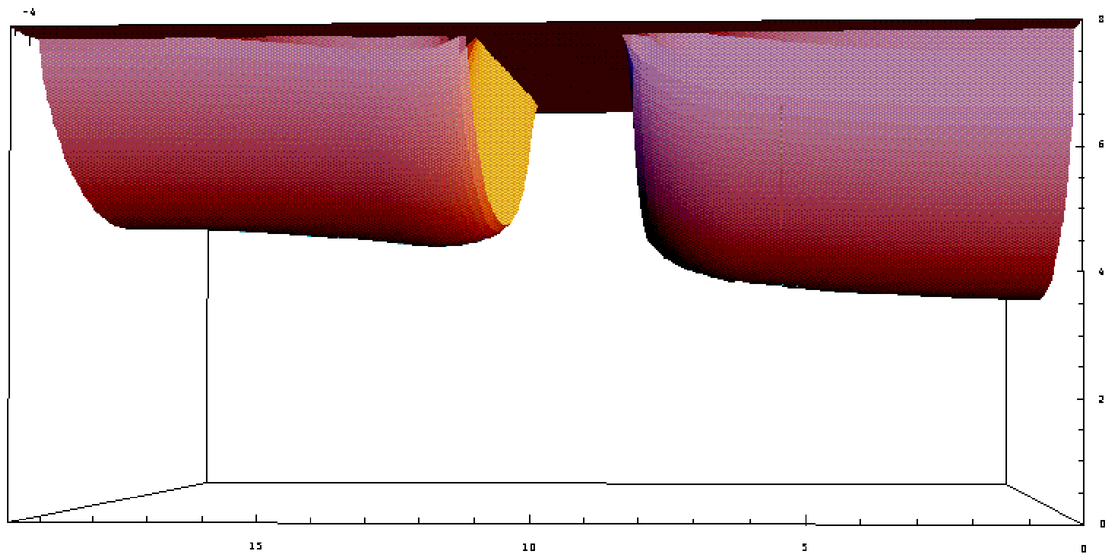


The main idea is to compute this last equation using a coarser mesh

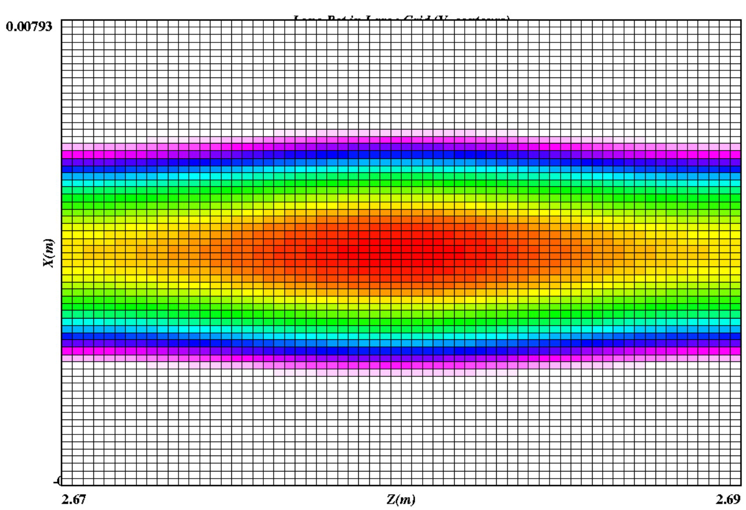
TOUTATIS: Typical output

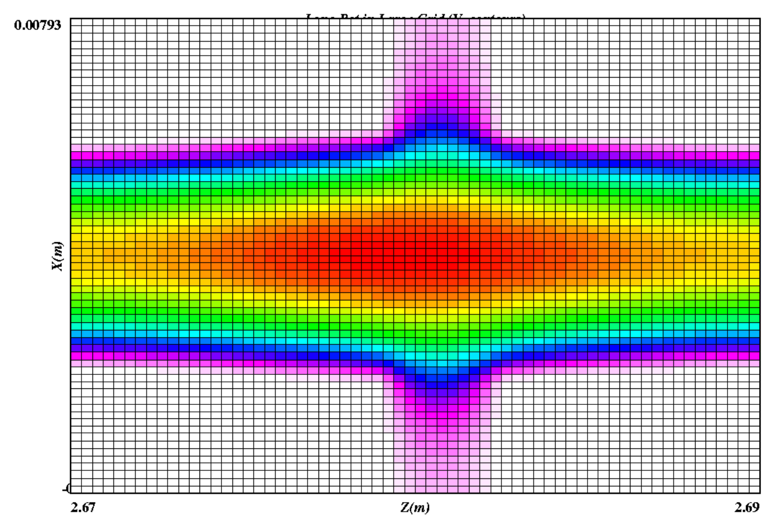


TOUTATIS: Coupling gaps



$$z = L_c \frac{|\Phi_s|}{\pi}$$





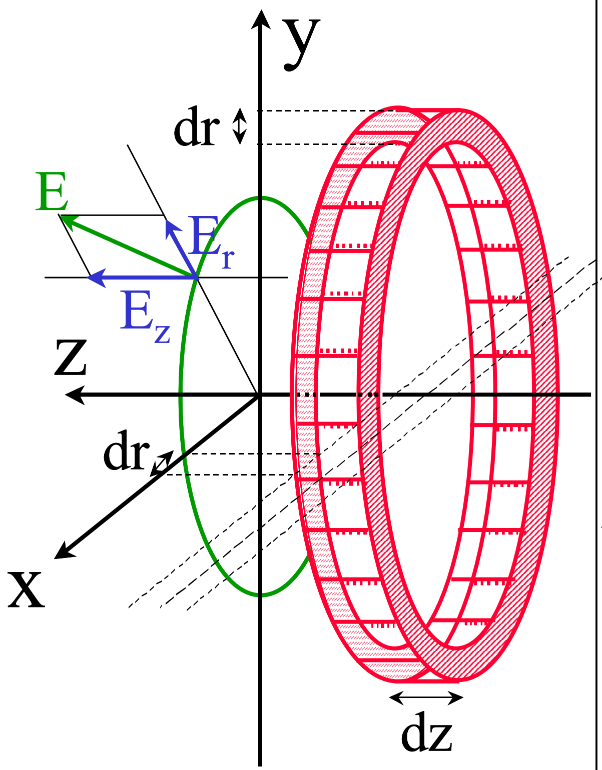
PARTRAN: The multiparticle code

Multiparticle (up to 10 millions) beam dynamics code.

- 3 space charge routines: SCHEFF, PICNIC, GAUSUP
- Outputs : Particle clouds. Beam losses, positions, sizes, emittances, halo along the linac. Phase advance, tune depression.
- Special elements : Multicell cavities, chopper, funnel, linear or non-linear continuous focusing channel, diagnostics.
- Special physics : Lorentz stripping, particle stripping and scattering on residual gas.

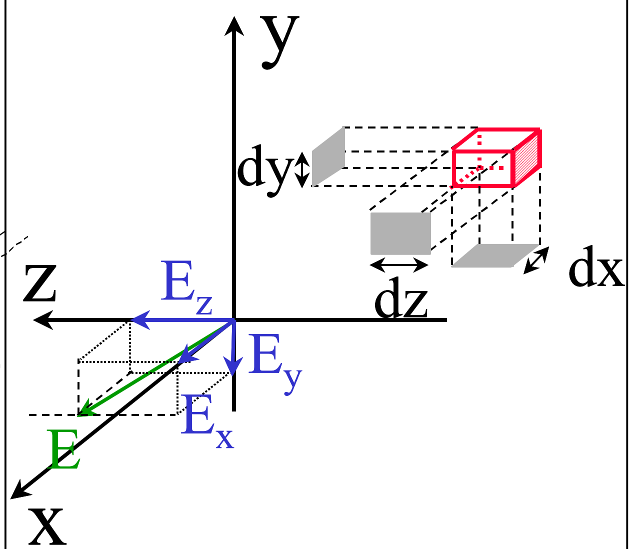
PARTRAN: Space-charge routines

SCHEFF
LANL-Parmila



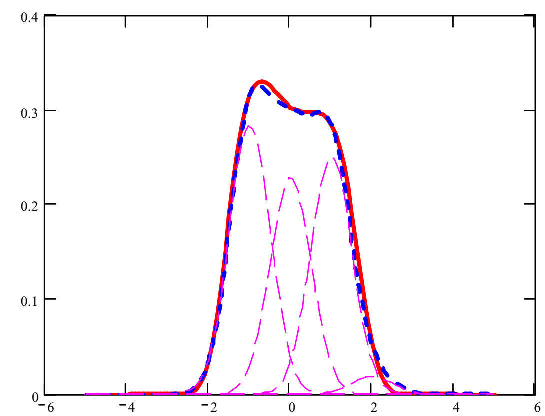
Interaction between rings
Cylindrical symmetry
assumed with SCHEFF

PICNIC
N. Pichoff, CEA-Saclay



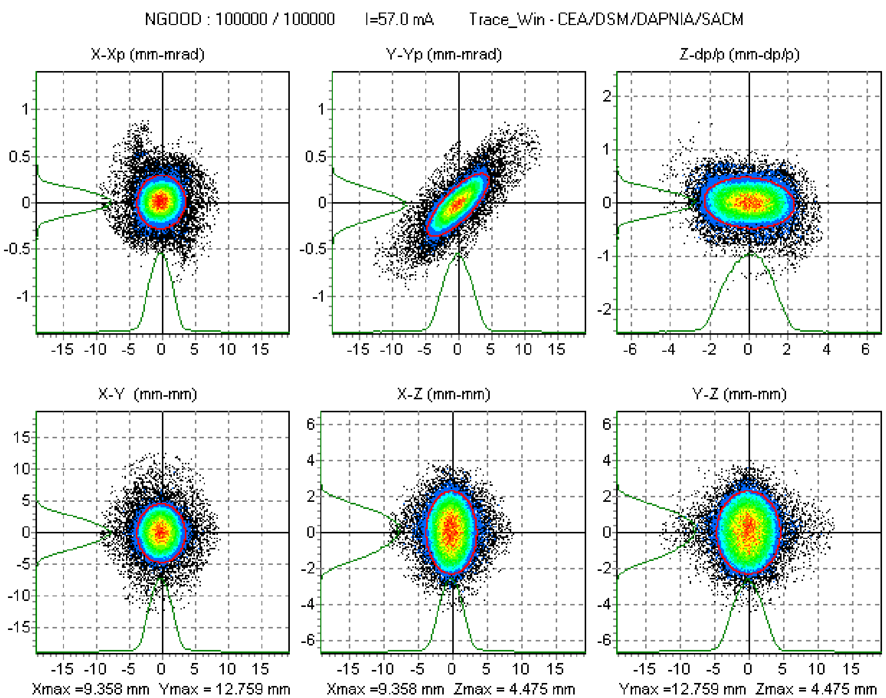
Interaction between cubes
NO symmetry assumed
with PICNIC

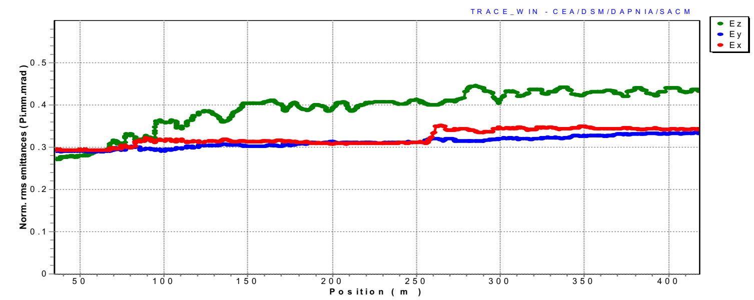
GAUSUP
J-L Coacolo, INP-Orsay

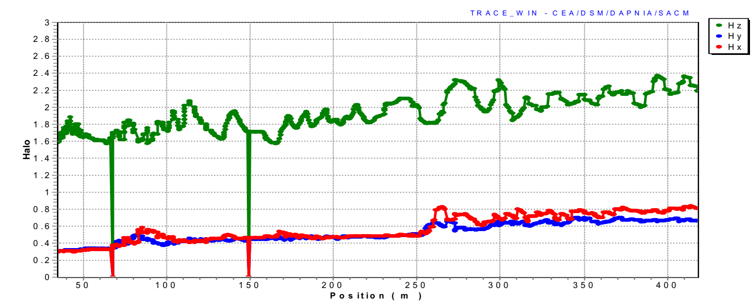


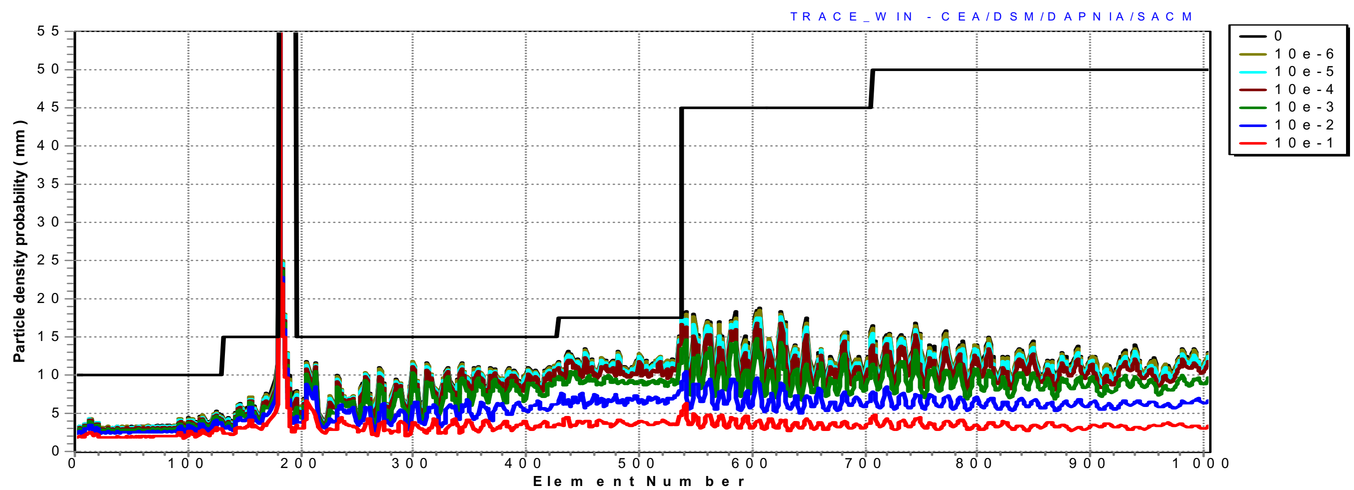
The distribution is modeled
by a sum of 3D gaussian
distributions

PARTRAN: Outputs









PARTRAN: Special elements

SACM

- Multi-cell cavity can be simulated with:
- Gaps, or
- A step-by-step integration in a sinusoidal field (SC cavities)

- A RF deviator (deviation depending on particle phase) is used for the ESS funnel cavity

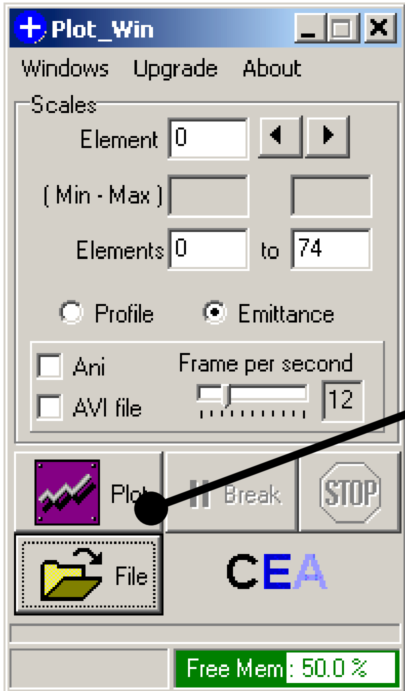
- A transverse continuous deviation can be put inside quadrupoles (ESS 352MHz chopper is placed inside quadrupoles)

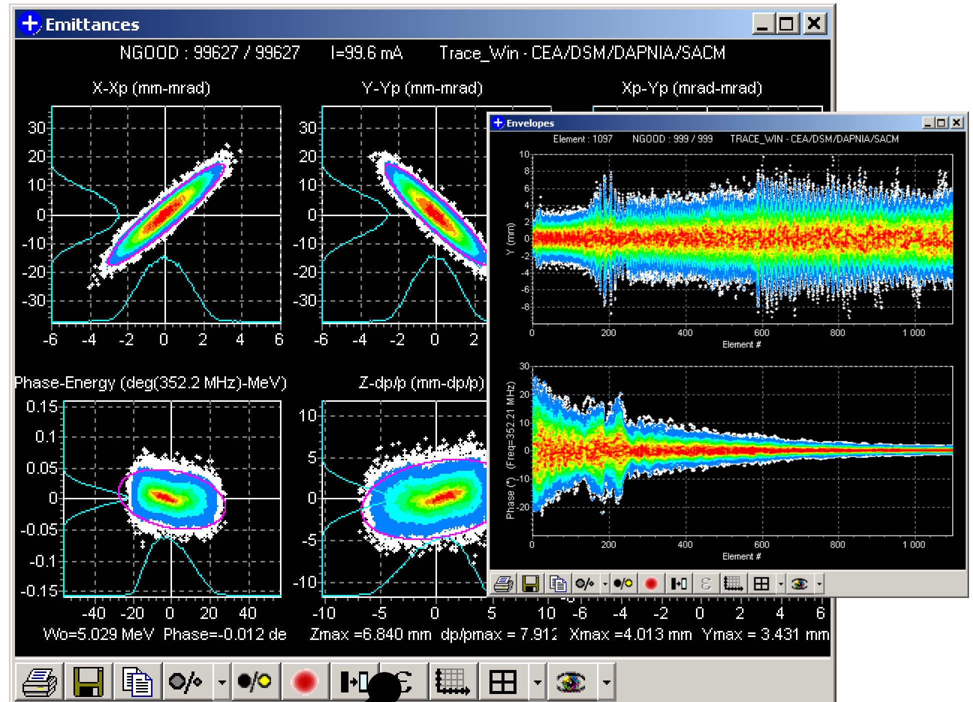
- A 3D continuous focusing channel can be used for beam physics studies. Non linearity can be introduced.

PARTRAN: Special physics

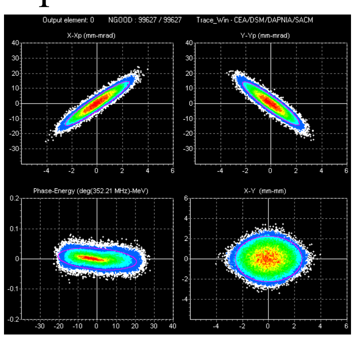
- Two beams with different charge and mass can be transported in the same linac (ESS H^- short pulse and H^+ long pulse).
- H^- stripping loss rate on residual gas can be estimated
- H^- Lorentz stripping loss rate on magnetic field can be simulated
- Beam scattering on residual gas can be simulated
- All these phenomena can be cumulated with each others and with linac elements errors.

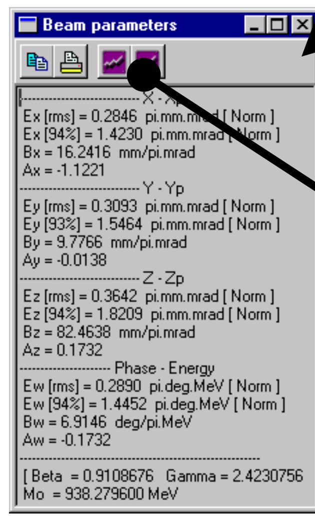
PlotWIN: The graphic interface

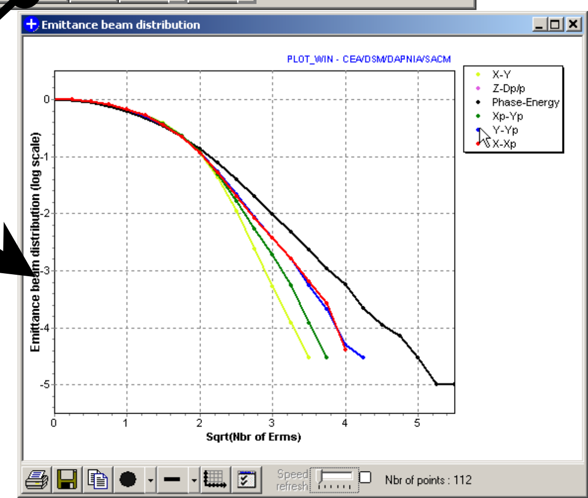




Zoom, hardcopy, save on disk, scale change, copy-paste tools can be used and Avi file can be create. You can select several particles and follow them.





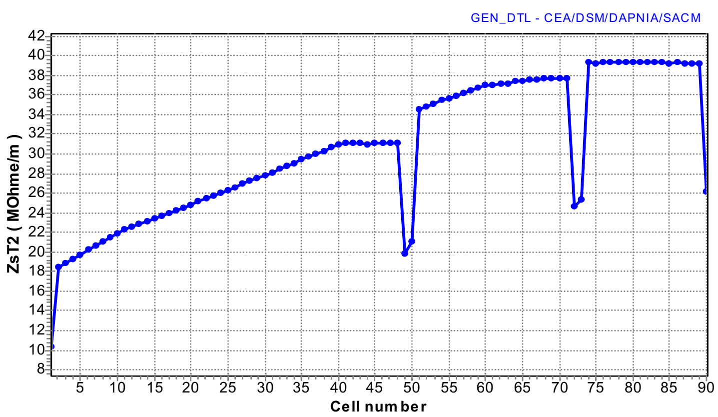


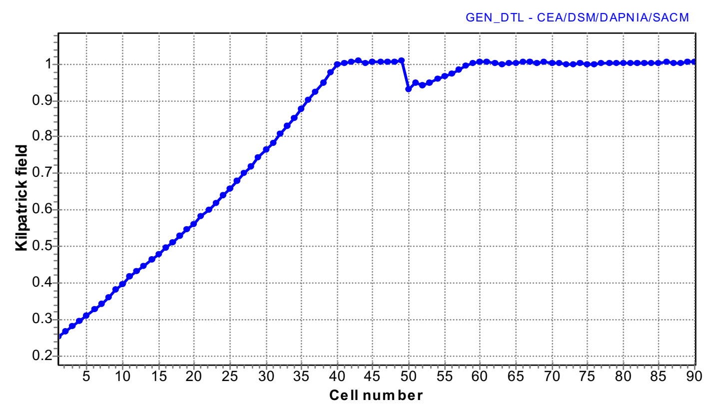
Example: IPHI DTL study

- DTL design with GenDTL
- Beam matching with TraceWIN
- Matched beam transportation with PARTRAN
- Error study with TraceWIN and PARTRAN

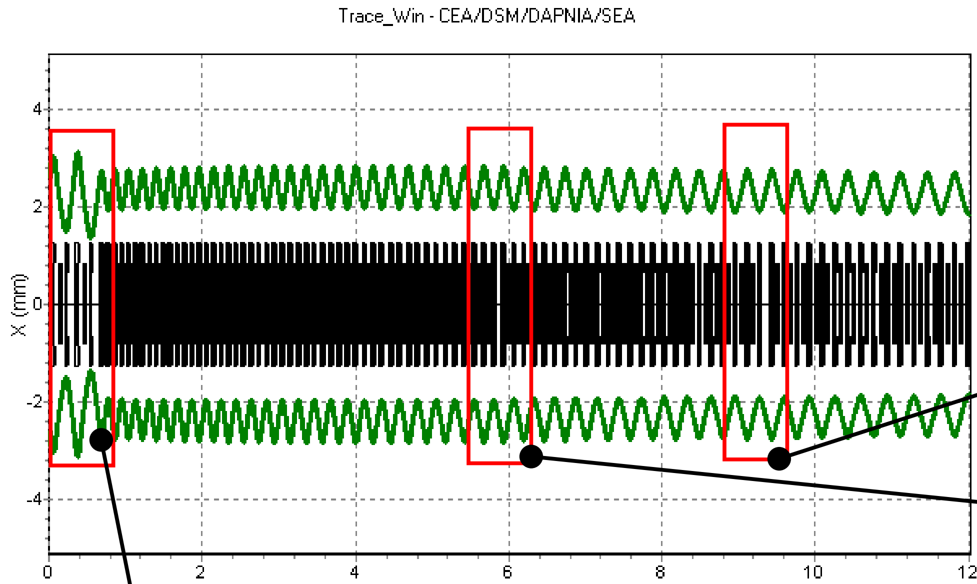
DTL design: GenDTL

- The DTL are generated by GenDTL in order to keep a continuity between the preceding RFQ (Same long. & tans phase advance).
- All the quadrupoles are the same for cost reducing.
- A maximum field limit is imposed.
- GenDTL calculated each cell geometry in order to minimize the dissipated power taking into account the quadrupole size (That mean each cell nose geometrie is adjusting in order to fit the quadrupole size but also to keep the maximum field below the limit asked).
- The quadrupole gradient are calculated by TraceWin in order to obtain the transverse phase advance law without current asked.

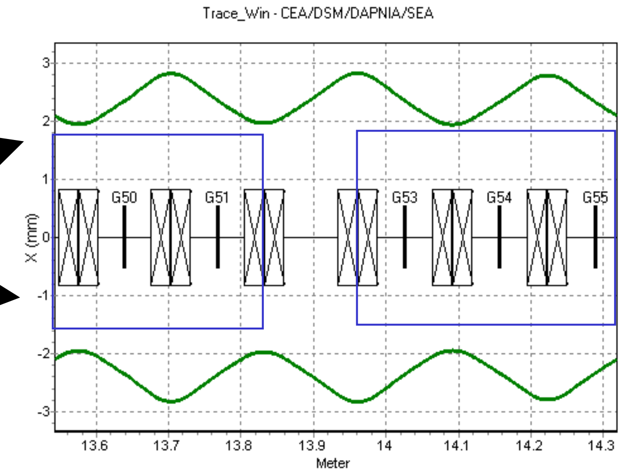


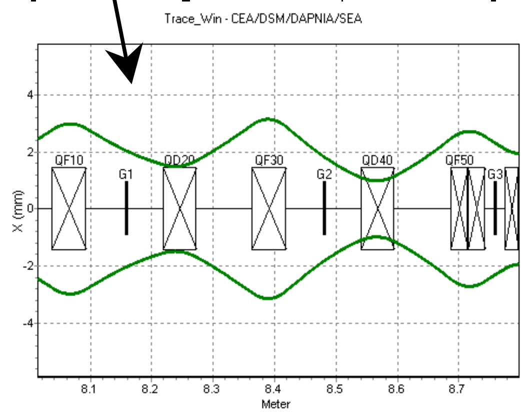


Beam Matching: TraceWIN



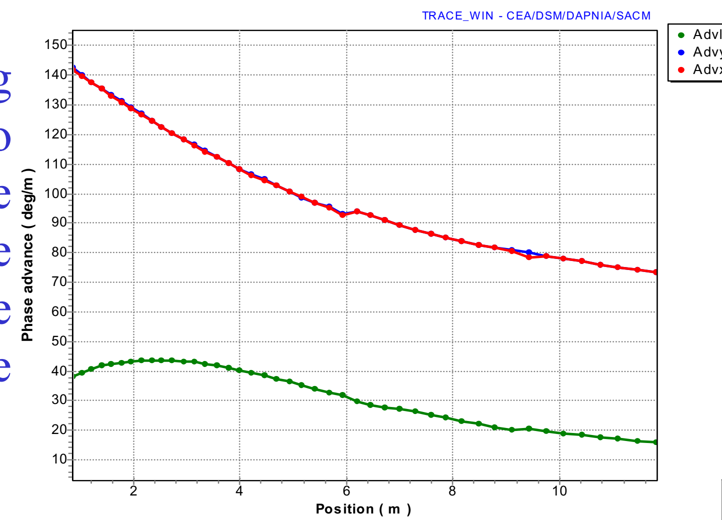
Automatic matching between between the 3 DTL tanks by adjusting the quadrupole gradient and synchronous phase of the the 2 last and first cells





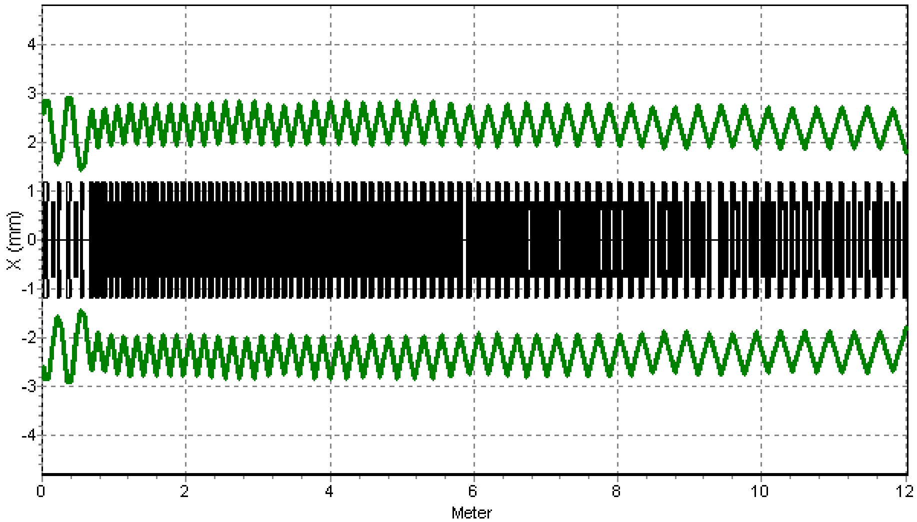
The 4 quadrupoles and 2 bunchers are automatically adjusted to match the beam distribution from the RFQ to the DTL.

The matching criterion is to smooth the longitudinal and the transverse phase advance

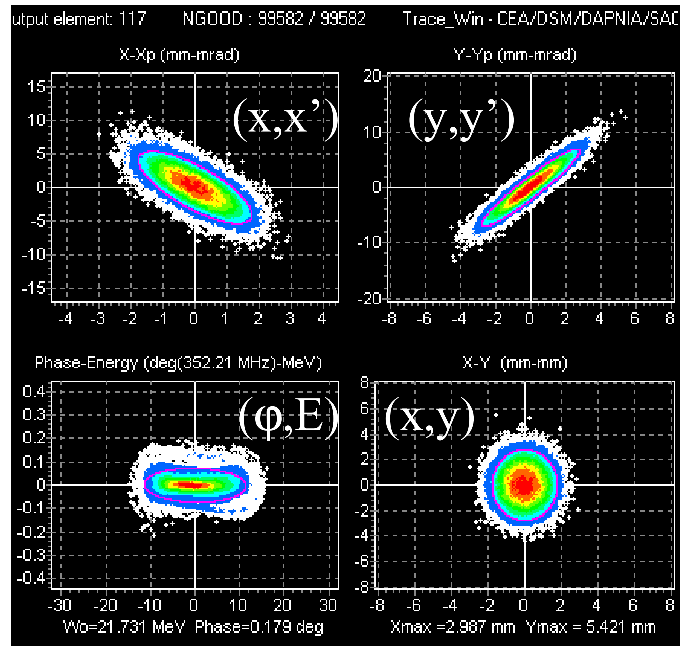


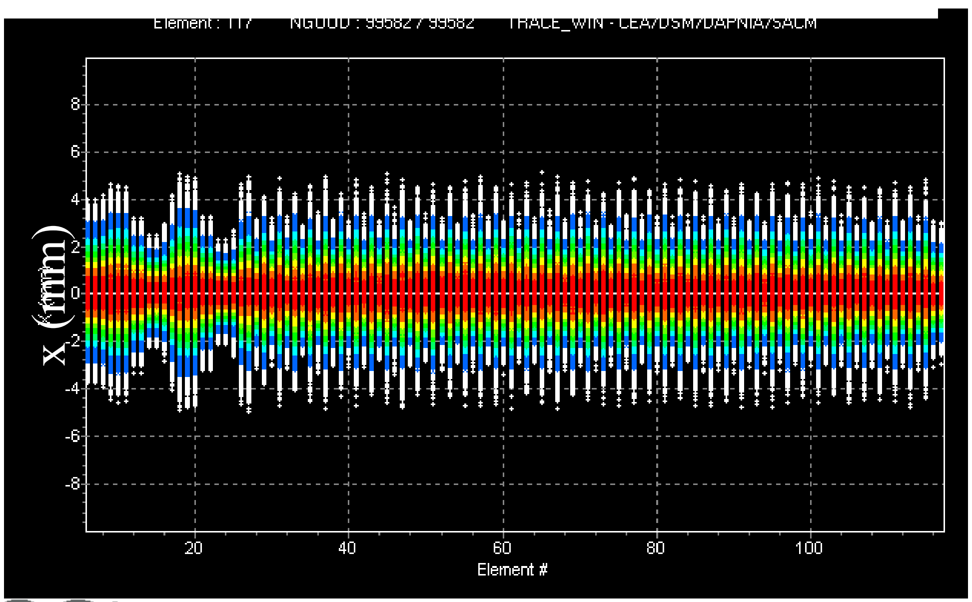
Multiparticle simulation: PARTRAN

Partran envelope



Output distribution

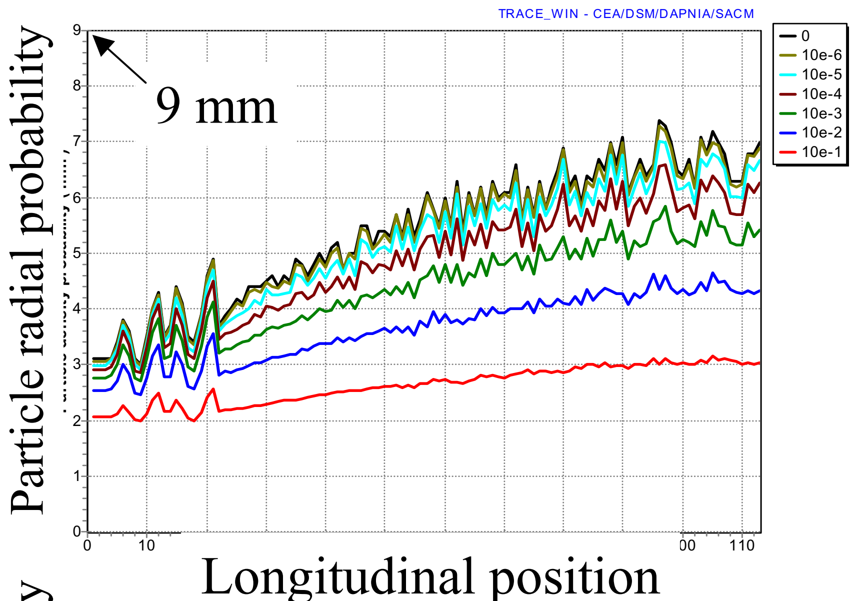


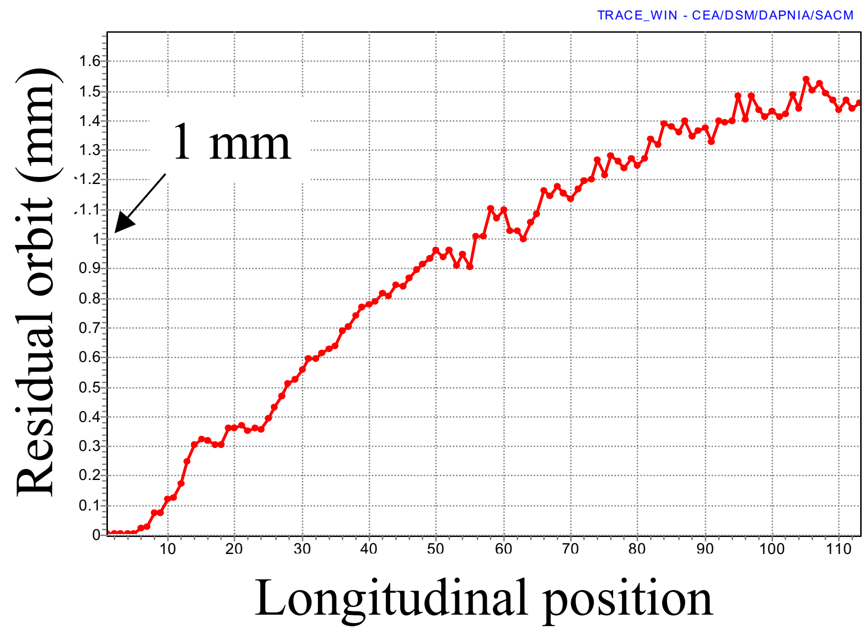


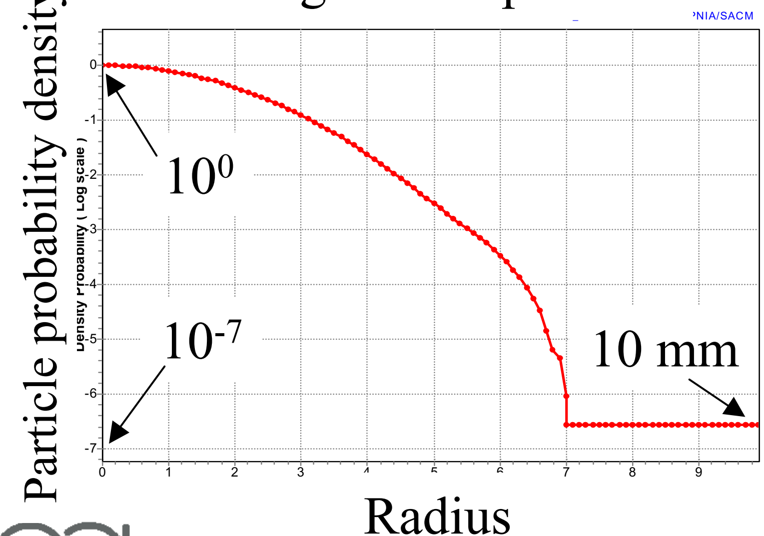
Beam profile
(100.000 particles)

Error study: TraceWIN & PARTRAN

Error study **without correction** (100 linacs of 10000 particles)







Error study: TraceWIN & PARTRAN

Error study **with correction** (100 linacs of 10000 particles)