Progress in the HIPPI code benchmarking

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for the HIPPI Working Package 5

CARE annual meeting, CERN, November 23 2005

Outline

- Motivations
- Used codes
- "Static comparison"
- Simulations of the UNILAC DTL section @ $I_b = 0$
- Simulations of the UNILAC DTL section @ $I_b = 37.5$ mA

Motivations

* Code comparison (SNS: for matched beam in a short section)

* benchmarking of codes necessary for predictions on beam loss in new high-current proton drivers

* Code benchmarking against transverse emittance growth measured @ GSI (attempt in LEDA; SNS & J-PARC in future)

The Project

The code comparison and benchmarking program had been proposed in the framework of the Working Package 5 of the European network HIPPI.

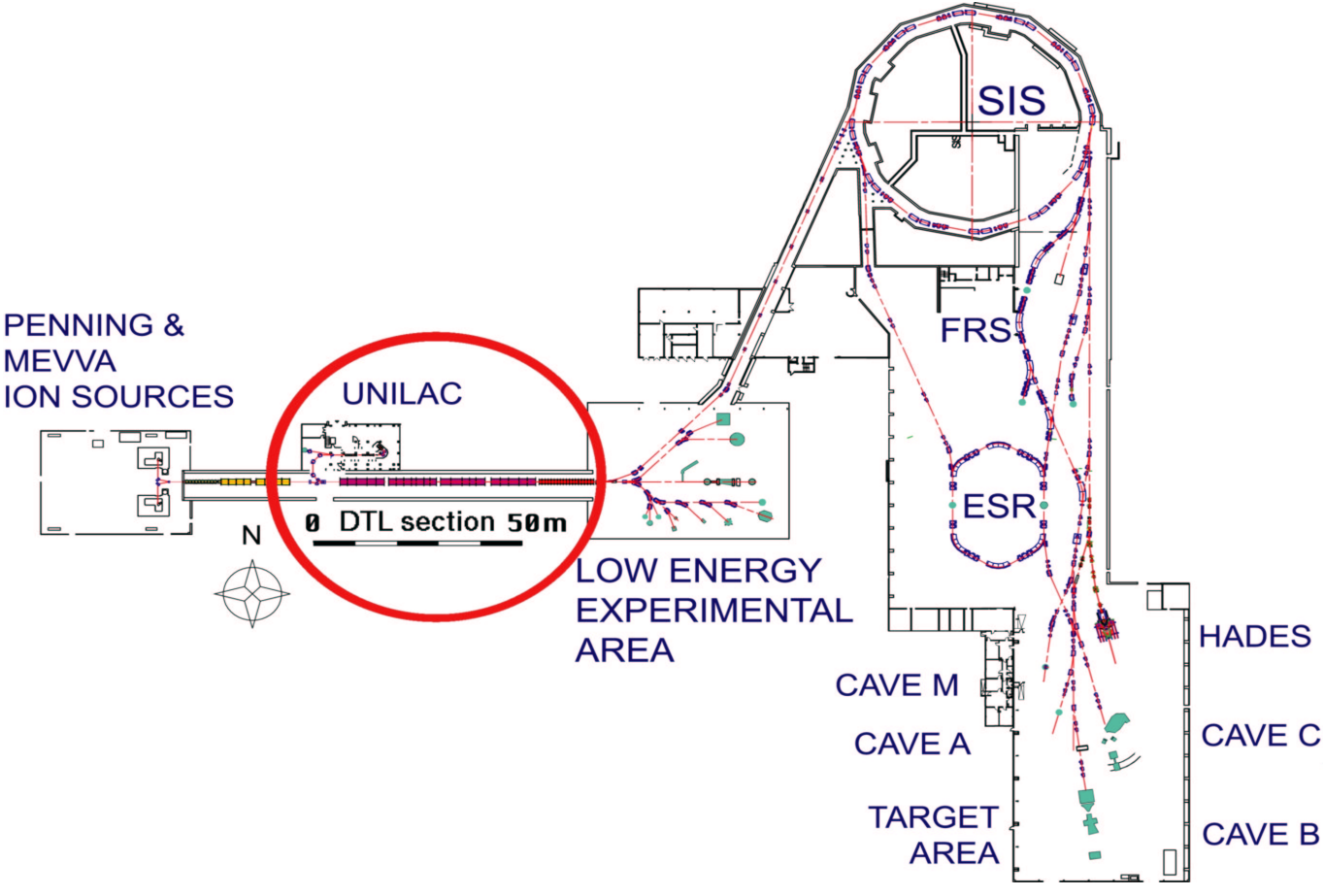
WP-5 Issues:

- **Validation and benchmarking of simulation codes**
- **Experiments on beam halo and emittance growth**
- **Diagnostics**
- **Beam Collimation**

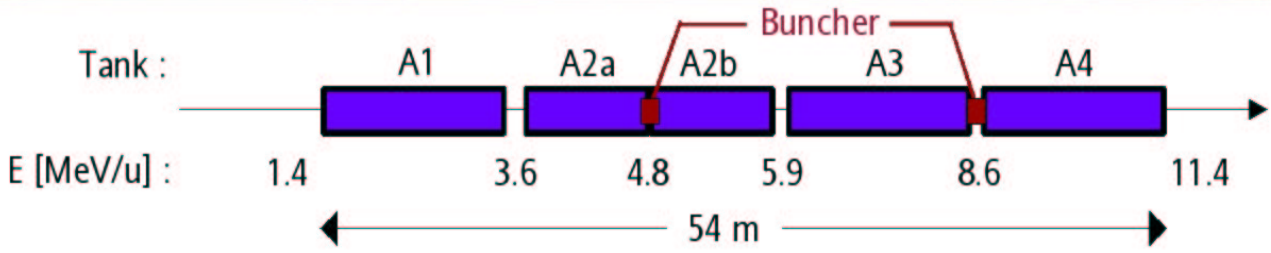
The benchmarking program:

- **Static comparison of different space charge solvers**
- **Tracking comparison using the DTL section of UNILAC**
- **Tracking simulations vs experimental findings from approved experiments (2006) →**

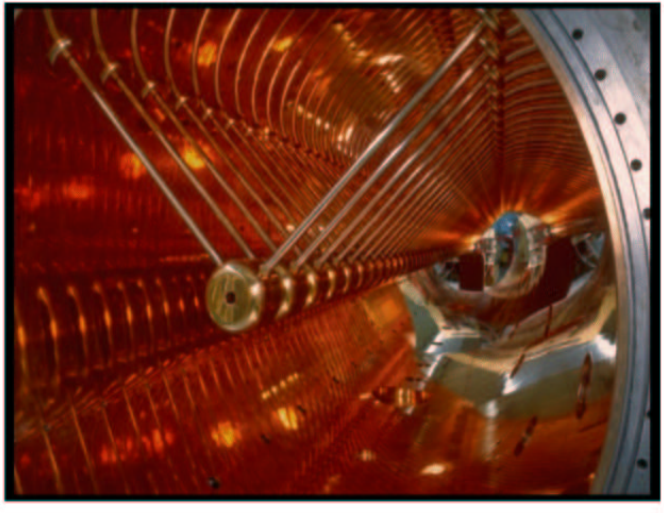
Alvarez DTL section of UNILAC at GSI



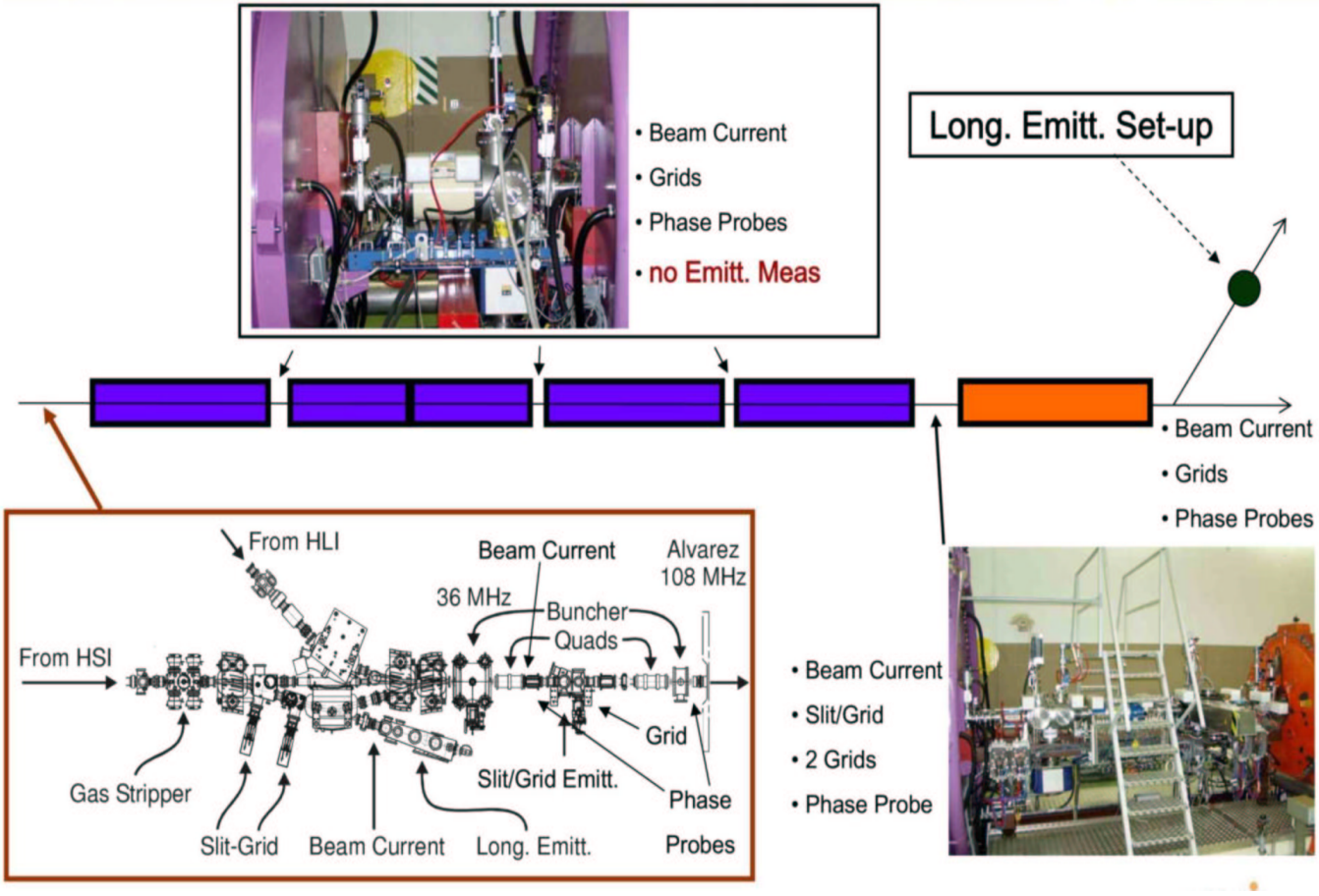
Alvarez DTL section of UNILAC at GSI



- 5 independent rf-tanks + 2 re-bunchers
- 108 MHz, 50 Hz, 5 ms
- 192 rf-cells
- DTL based on F-D-D-F focusing
- dc-quads grouped to 13 families
- Inter-tank focusing : F-D-F
- Transv. acceptance (norm.) = 15 μm
- Synchr. rf-phases -(30°,30°,30°,25°,25°)



Alvarez DTL section of UNILAC at GSI

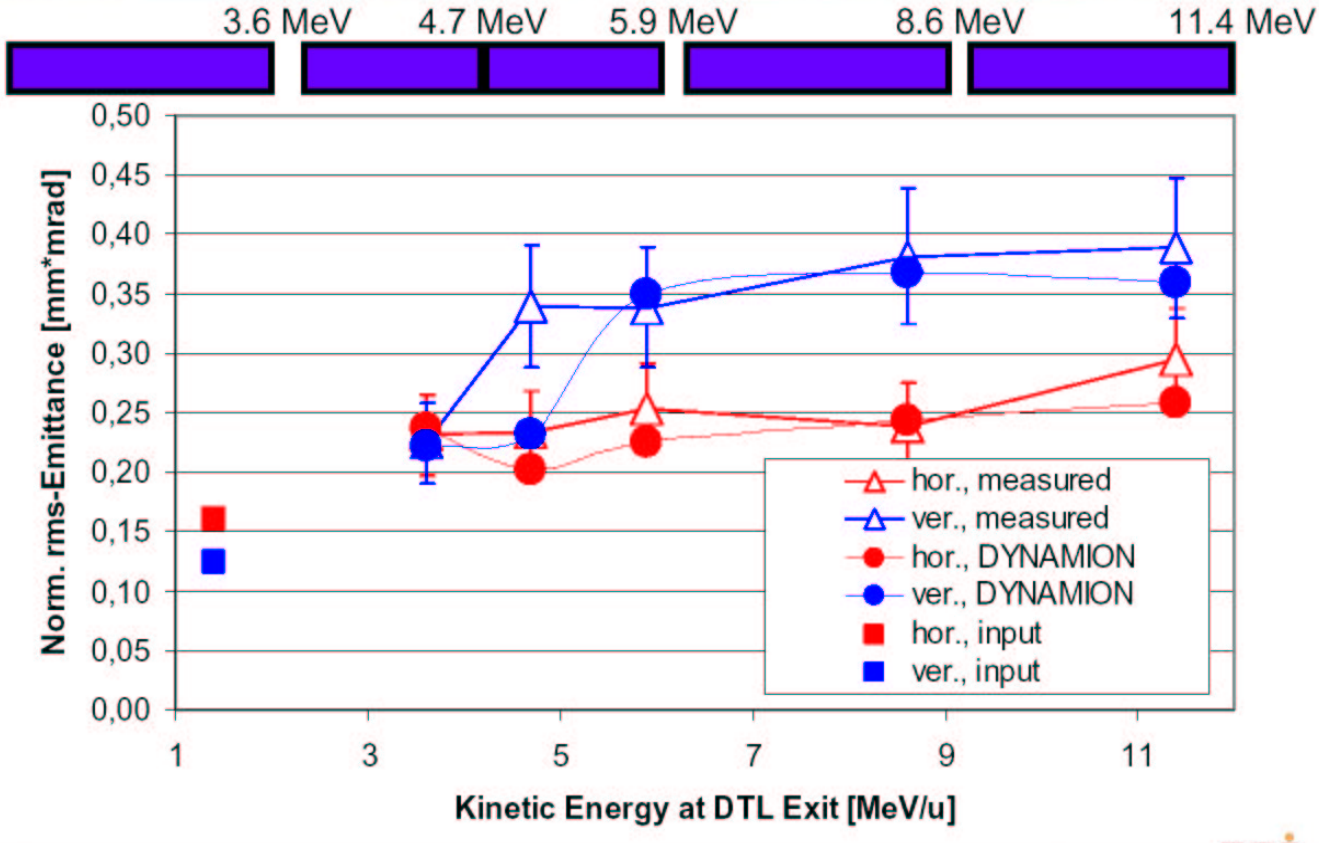


Measurement of emittance growth in the DTL section of UNILAC

In order to obtain information on the inter-tank emittances
we applied the following procedure:

- switch off the rf of tanks which are down stream with respect to position of interest
- resulting de-bunching should lower space charge forces rapidly
- measure the emittance at existing set-up after last DTL tank
- measurements with different currents & rf-powered tanks

Experiment & Simulations, High Current, *Mar05*



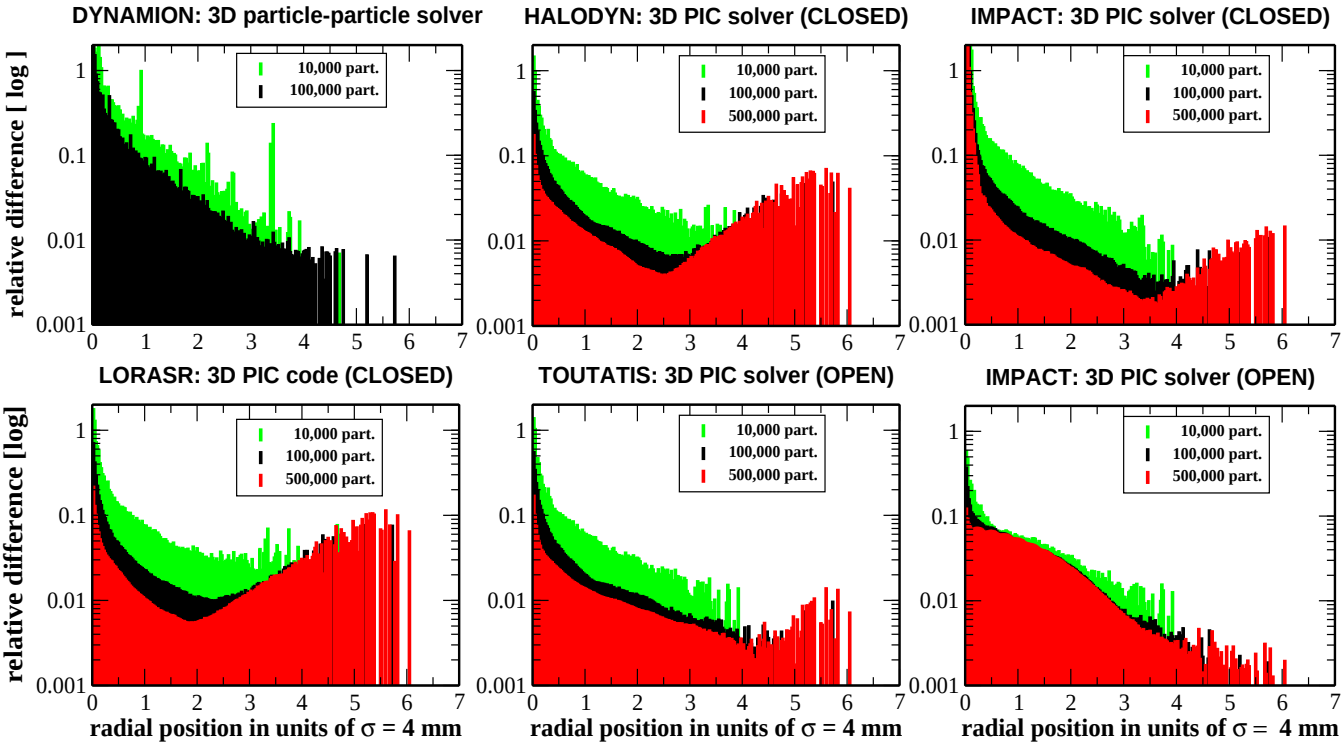
USED CODES

alphabetic order

- **DYNAMION (ITEP, GSI)**
- **HALODYN (U. Bologna, LNL)**
- **IMPACT (LANL, LBNL)**
- **LORASR (U. Frankfurt, IAP)**
- **PARMILA (LANL)**
- **PARTRAN (CEA, Saclay)**
- **PATH (CERN)**
- **TOUTATIS (CEA, Saclay)**

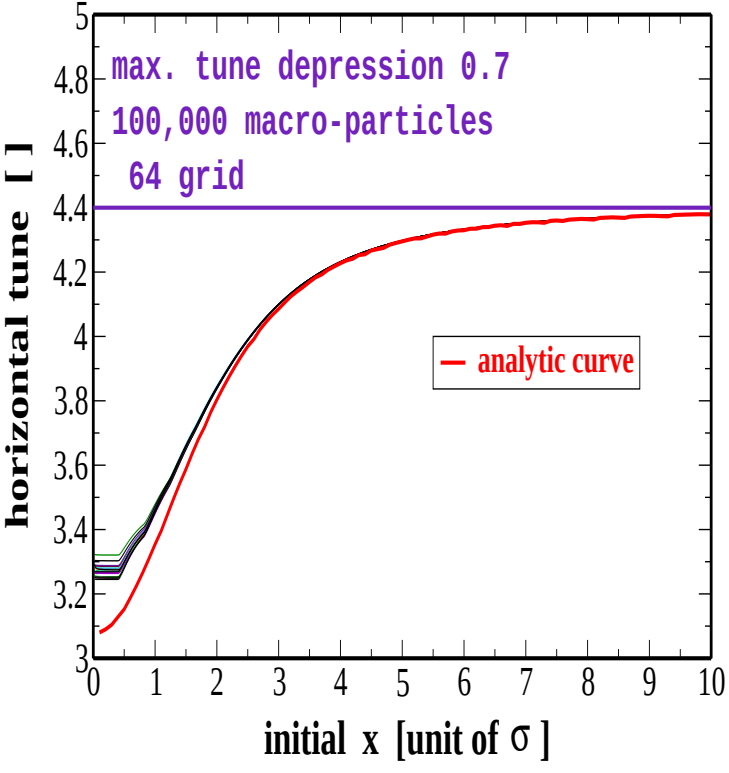
Electric Field Comparison: $\frac{\delta E}{E}$ 128-grid

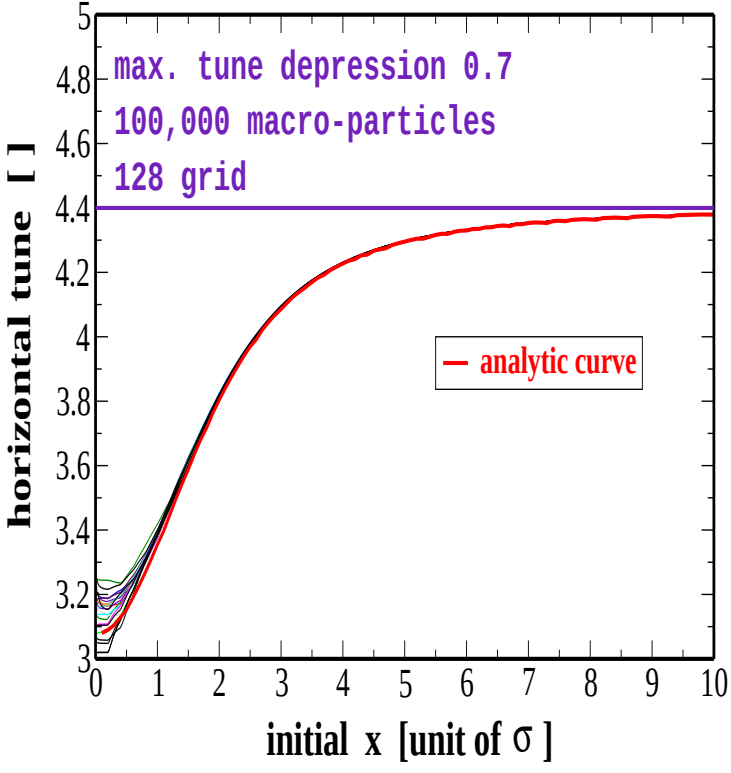
6D Gaussian bunch $\sigma_x = \sigma_y = \sigma = 4$ mm, $\sigma_z = 2\sigma$, 128-GRID, boundary @ 8σ



Single Particle Tune (SPT): PIC Simulations

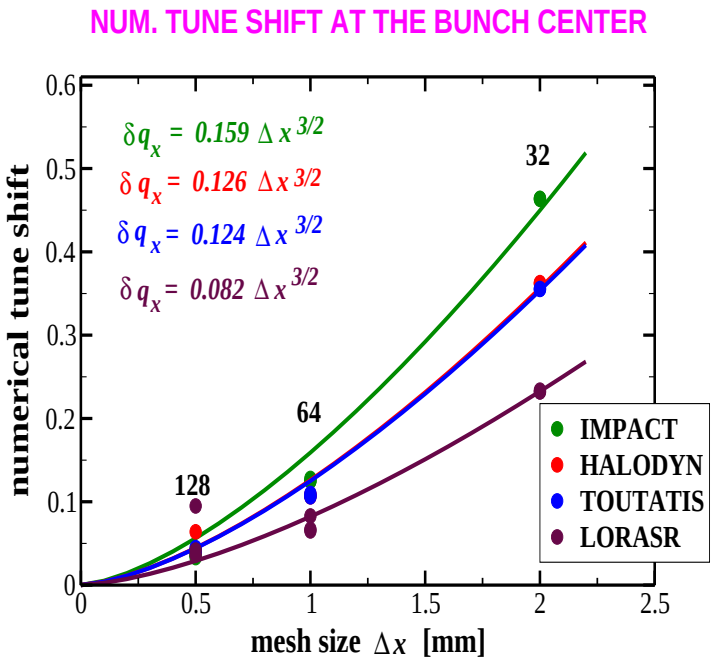
$$\delta q = \frac{K_1(\mathbf{code}, \mathbf{test})}{\sqrt{\Delta x^3 N_p}} + K_2(\mathbf{code}, \mathbf{test})\Delta x^{3/2}$$

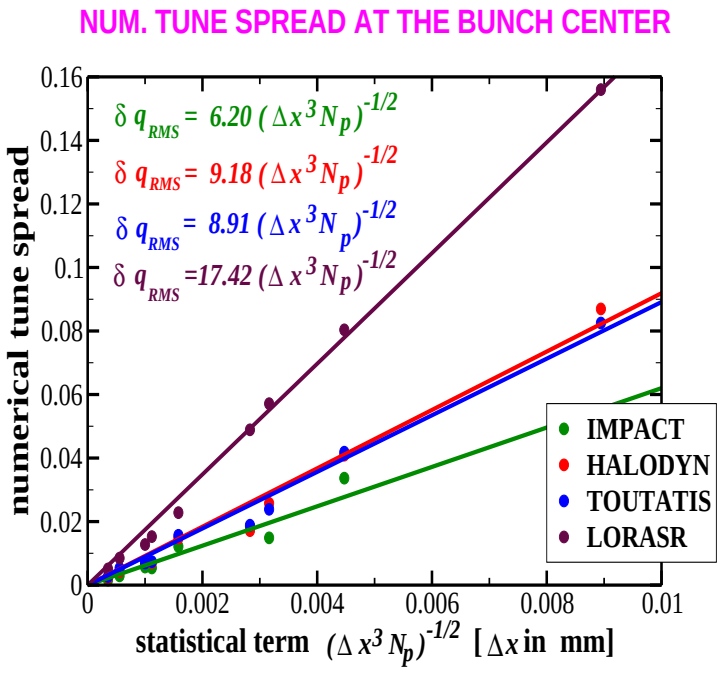




Gaussian distribution, 20 random seeds

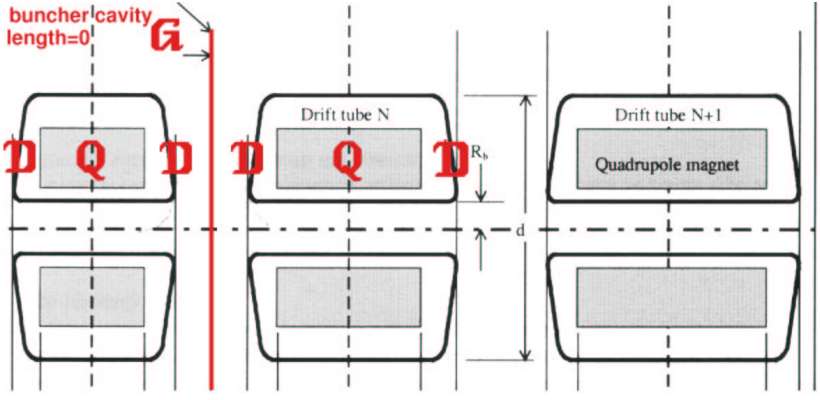
Numerical Tune Shift & Spread





UNILAC DTL tracking simulations

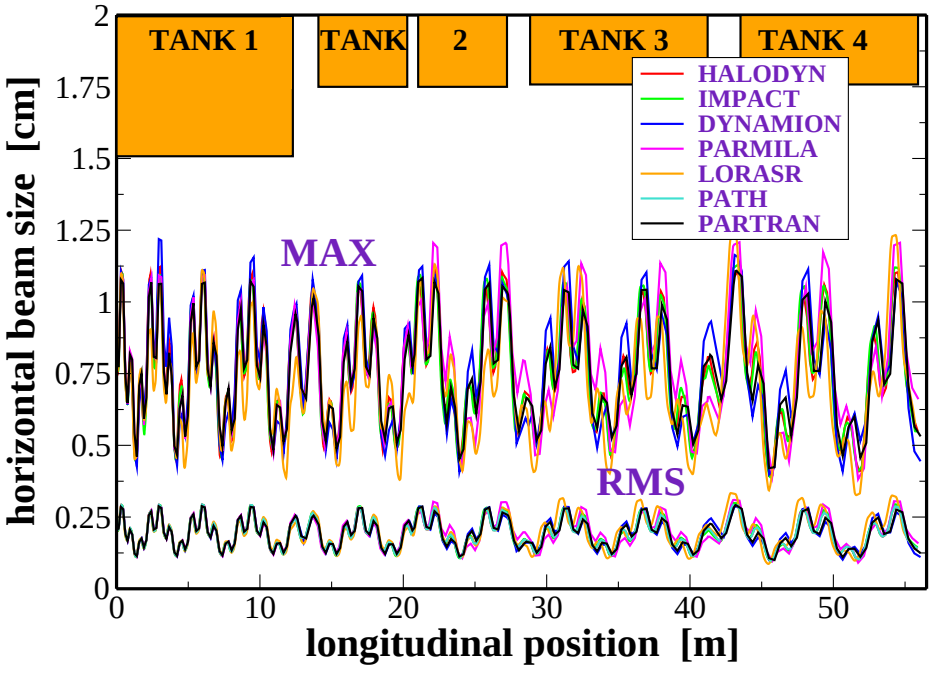
- the 178 DTL cells have been simulated with
  Superfish: TTF tab. for PARMILA , RF map for IMPACT
  Microwave Studio: EM field map for LORASR
- HALODYN, PATH, PARTRAN: DTL cell split in Q, D, G



- existing external files with DTL geometry for DYNAMION
- first tracking comparison without space charge $I = 0$ $\rightarrow$

UNILAC Alvarez section: tracking @ $I = 0$

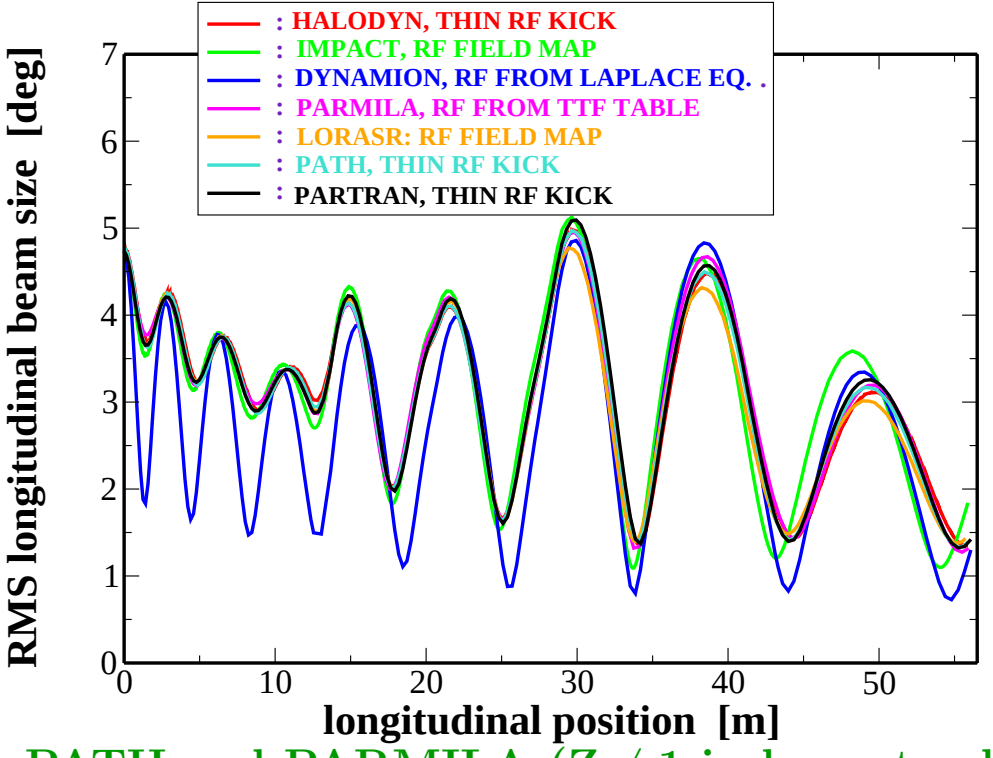
6D Gaussian bunch $\sigma_x = \sigma_y = \sigma_z = 2$ mm: horizontal beam sizes



bugs fixed in HALODYN (Z $\neq$ 1 in QUAD)

UNILAC Alvarez section: tracking @ $I = 0$

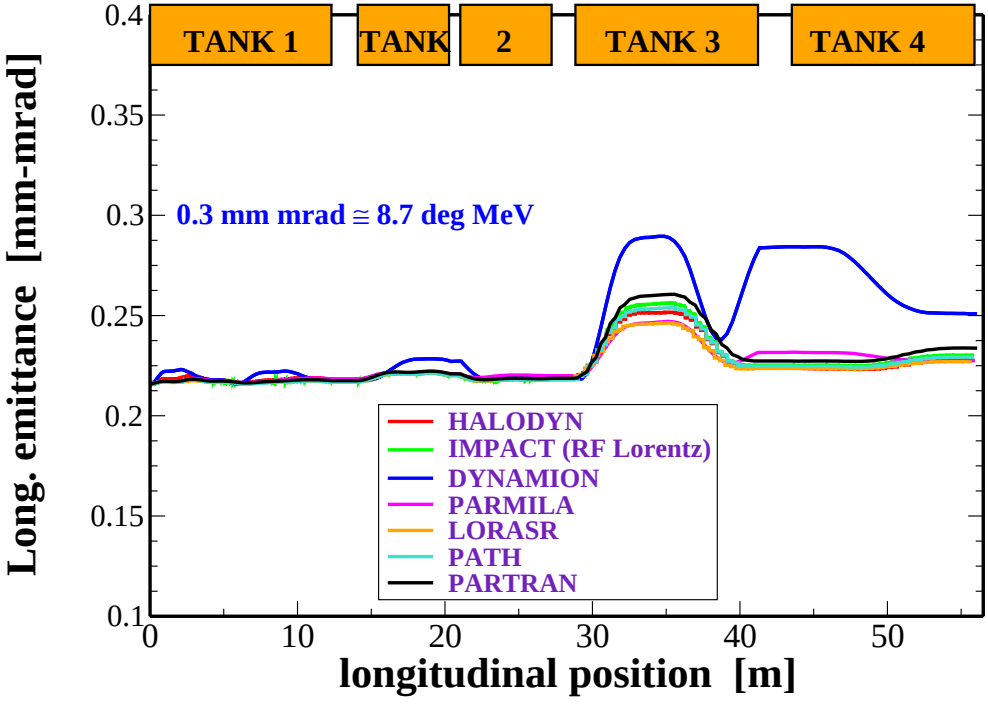
6D Gaussian bunch $\sigma_x = \sigma_y = \sigma_z = 2$ mm: longitud. beam sizes



bug fixed in PATH and PARMILA ($Z \neq 1$ in long. tracking)

UNILAC Alvarez section: tracking @ $I = 0$

6D Gaussian bunch $\sigma_x = \sigma_y = \sigma_z = 2$ mm: longitud. emittance



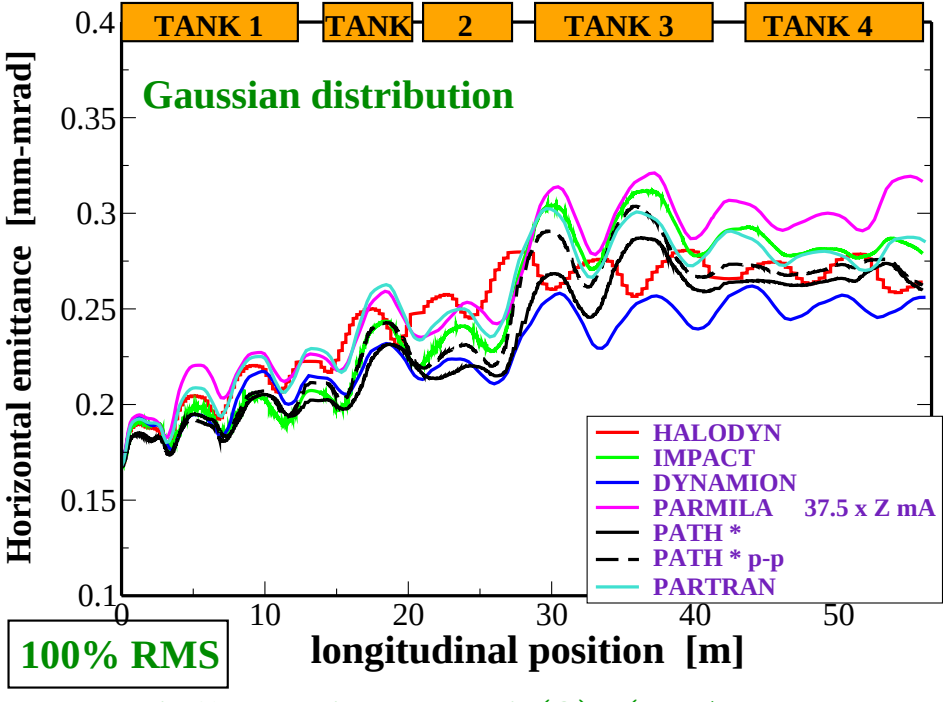
UNILAC Alvarez section: tracking with s.c.

- $^{238}U^{28+}$, $I_b = 37.5$ mA
- T=1.4 MeV/u
- 6D Gaussian bunch $\sigma_x = \sigma_y = \sigma_z = 1.75$ mm
- hor. tune depression $\Delta\Phi^t/\Delta\Phi_0^t \simeq 0.55$
- ver. tune depression $\Delta\Phi^z/\Delta\Phi_0^z \simeq 0.35$!!
- # of macroparticles:
  - 10^6 IMPACT* [$\sim$ 4 days], HALODYN* [$\sim$ 20 h] (3D)
    PARTRAN [$\sim$ 6 days] (3D)
  - 10^5 PARMILA,PATH [$\sim$ 1,5 h] (2D r-z)
  - 5×10^3 DYNAMION [$\sim$ 1,3 days] (P-P)
  - 2×10^4 PATH [$\sim$ 1,5 days] (P-P)

*: to be scaled with # of CPU's

UNILAC Alvarez section: tracking with s.c.

Hor. RMS emittance tune depression $\simeq (0.55, 0.35)$

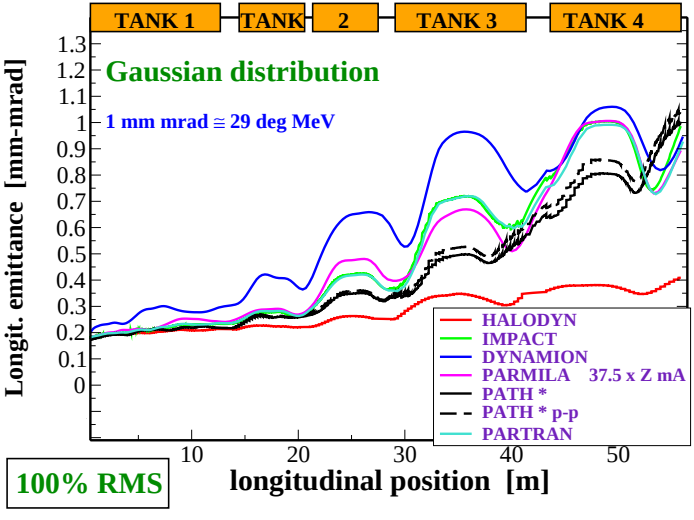


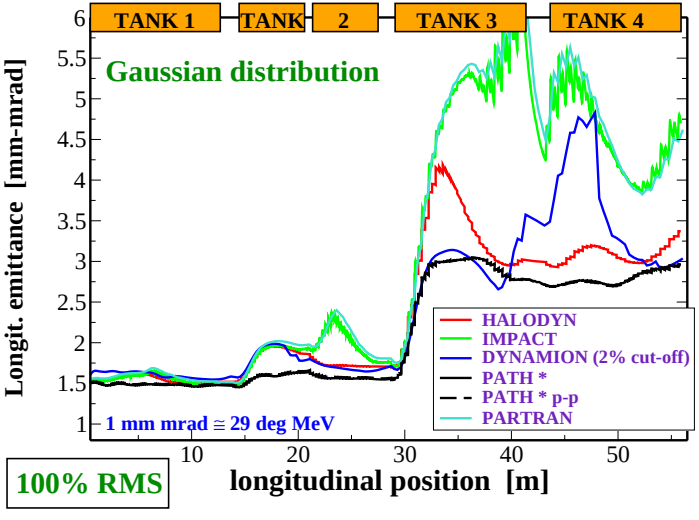
bug fixed in IMPACT, PARMILA(?) ($Z \neq 1$ in Poisson solver)

UNILAC Alvarez section: tracking with s.c.

Severe long. tune depression ⇔ large discrepancies for ϵ_z?

tune depr. $(0.55, 0.35)$ **tune depr. $(0.67, 0.88)$**



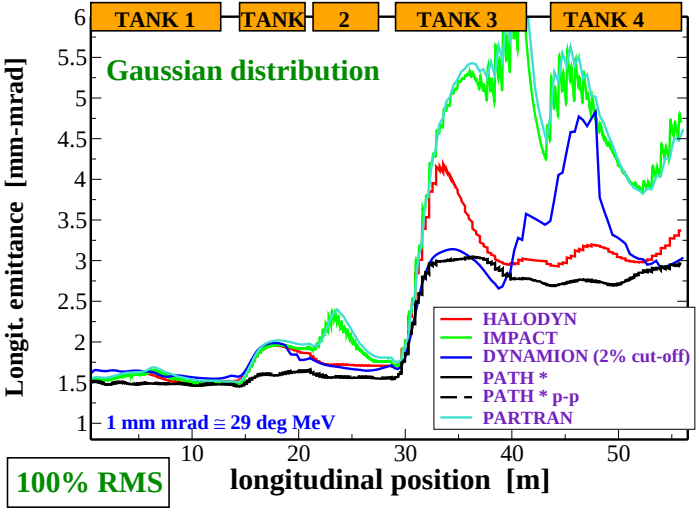


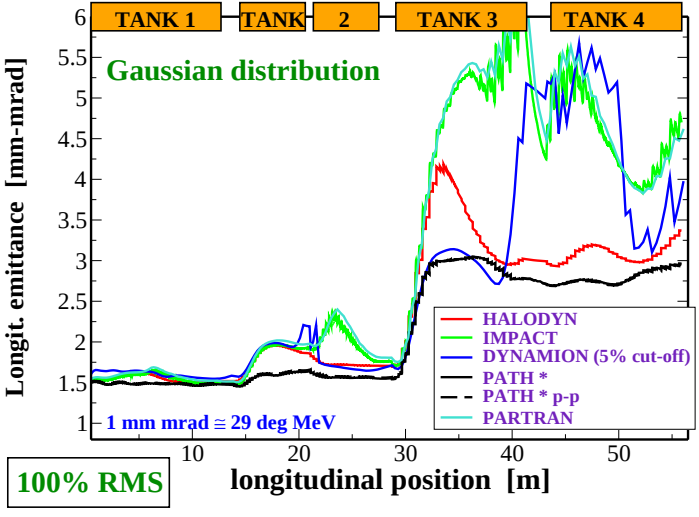
$\epsilon_{z0} = 0.168$ mm mrad $\epsilon_{z0} = 1.5$ mm mrad

bug fixed in PATH (energy gain ⇔ PIC Poisson solver)

UNILAC Alvarez section: tracking with s.c.

Is ϵ_z a good observable in case of "long. losses"? Few particles close to the long. separatrix $\Leftrightarrow$ large ϵ_z?





cutoff @ 2% pulse length

0.54% (27) long. losses

DYNAMION

cutoff @ 5% pulse length

0.52% (26) long. losses

IMPACT(π): 1.9% HALODYN: 3.8% PATH: 0.0% PARTRAN(π): 2.0%

UNILAC tracking: summary & outlook

- **Tracking @ $I_b = 0$ for lattice modeling completed**
  - very good agreement, RF in 3rd tank to be better checked
  - Code debugging mostly related to $Z \neq 1$
- **Tracking simulations @ $I_b = 37.5$ mA of a mismatched beam:**
  - Remarkable agreement IMPACT-PARTRAN
  - emittance growth: difference within 50% among all codes
  - Factor Z in Poisson solver of IMPACT and PARMILA (to be confirmed, problems running 2nd case)
  - PATH: fixed problems of energy gain $\Leftrightarrow$ PIC Poisson solver
  - HALODYN: long. closed boundary conditions $\Rightarrow$ problems with severe depressed tune
  - LORASR: coming soon with new Poisson solver
- Long. particle loss management to be clarified
- Beam matching with space charge started (TRACE 3D,PATH?)