# Optimization of Gun Parameters

Jörg Kewisch

(Thanks to X.Y.Chang and D. Abell)

What to optimize

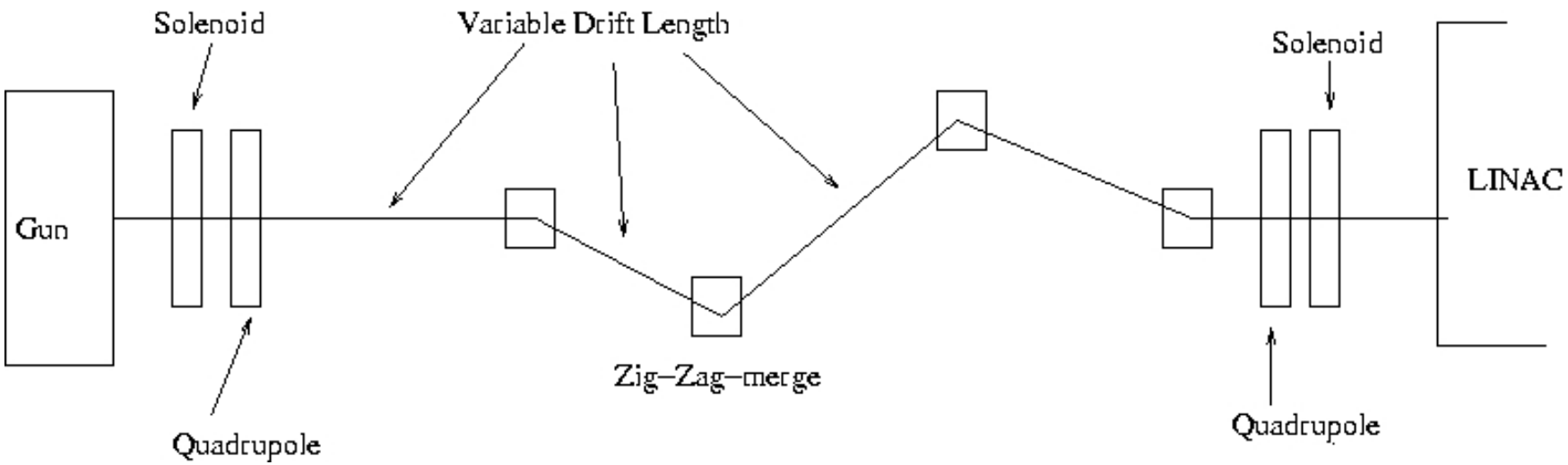
Strategy

Optimizers

PARMELA vs. ImpactT

BROOKHAVEN
NATIONAL LABORATORY

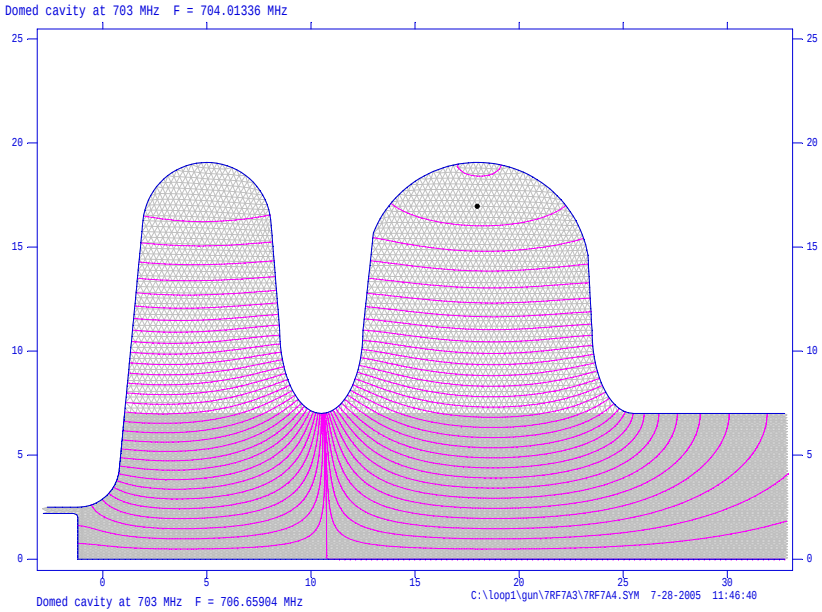
# Cooler ERL Injector

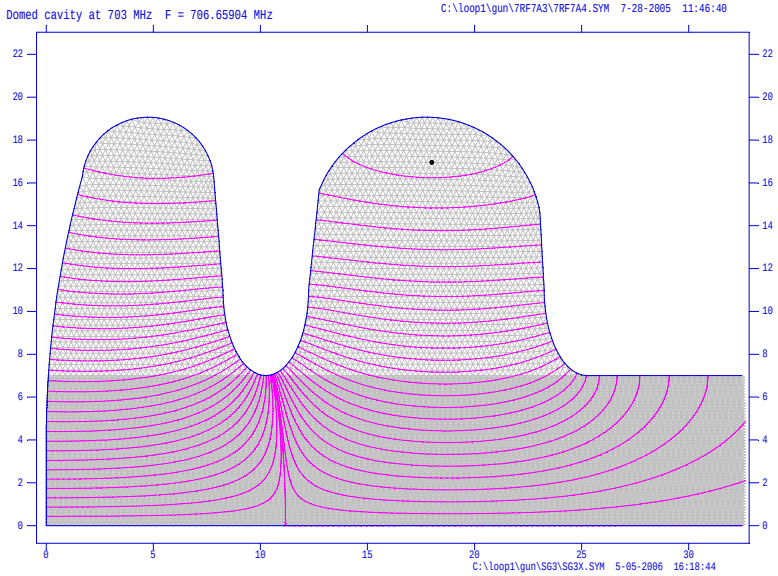



Also variable:

- Bunch shape
- Bunch length
- Launch Phase
- Gun shape

# Gun shape



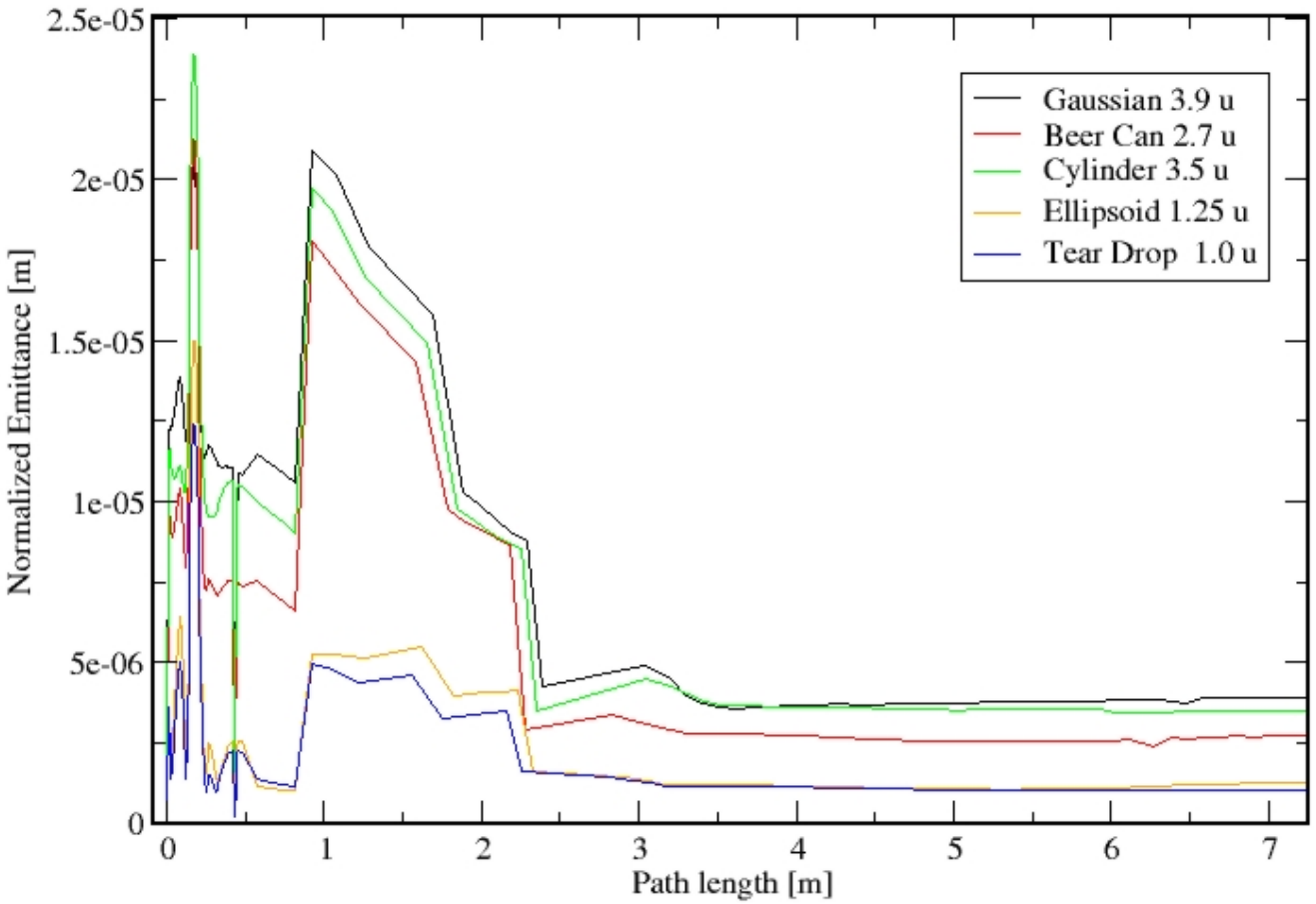




- All calculations are done with a 1½ cell gun with recessed cathode.
- The non-linear RF fields influence the emittance
- A gun without recess was tested. The slice emittances at the exit of the gun did not improve, but the beam size at the exit of the gun is 3 times larger, producing stronger chromaticity effects after the gun.

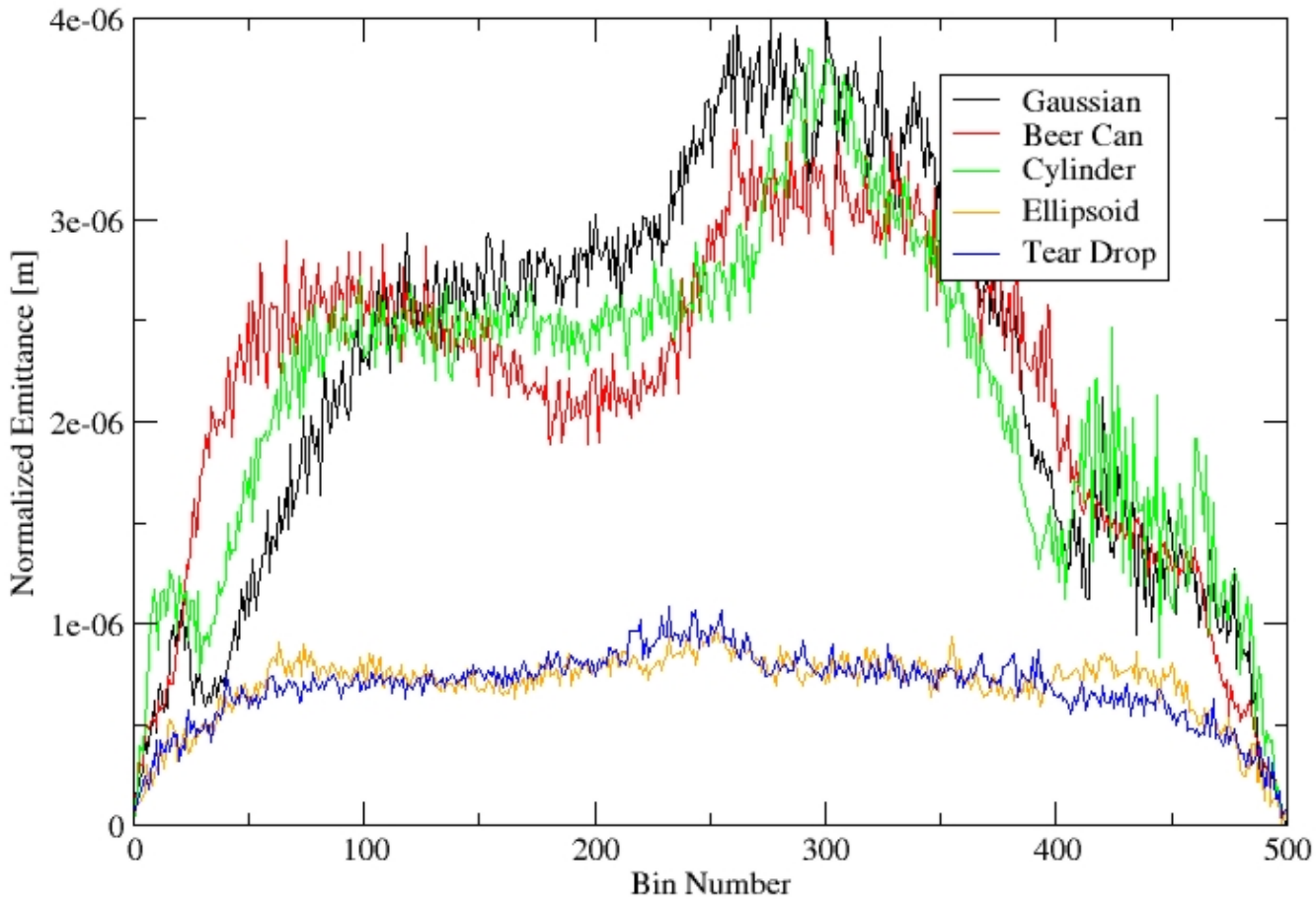
# Bunch shape

| Type | Radial shape | Longitudinal density | Number of parameters |
|---|---|---|---|
| Gaussian | Cylinder | Gaussian | Radius, Length |
| Beer Can | Cylinder | Uniform | Radius, Length |
| Cylinder | Cylinder | 2 half Ellipses | 2 ellipse axis, Radius, Length |
| Ellipsoid | Ellipse | Uniform | Radius, Length |
| Tear Drop | Two Ellipses + line | Uniform | 4 ellipse axis, Length |

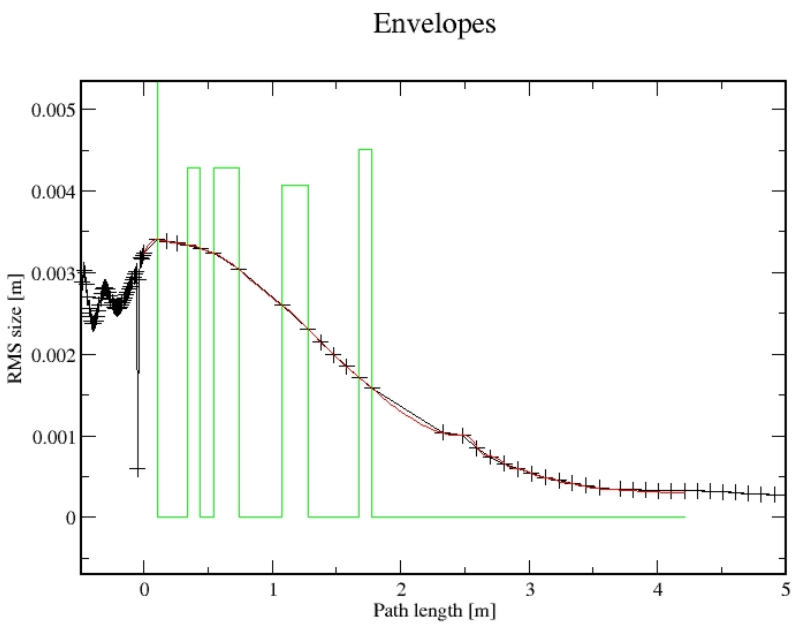
# Results

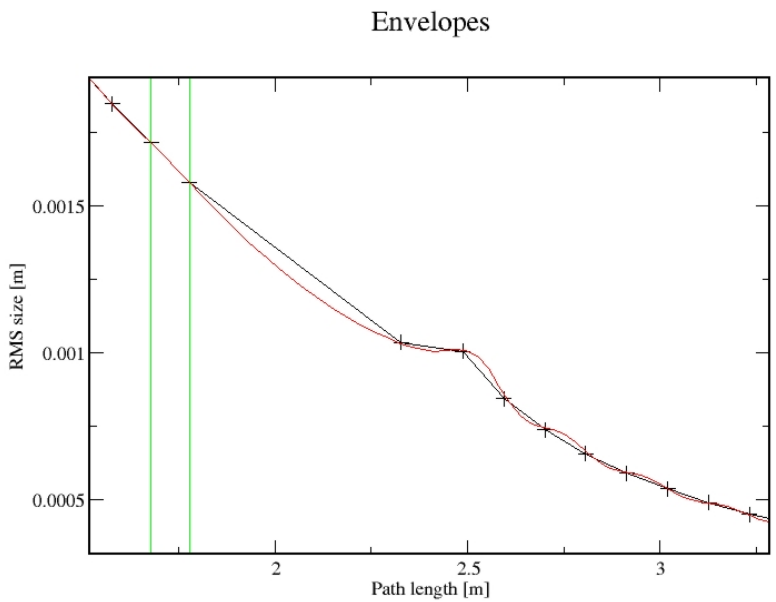

Gaussian 3.9 u
Beer Can 2.7 u
Cylinder 3.5 u
Ellipsoid 1.25 u
Tear Drop 1.0 u
Normalized Emittance [m]
Path length [m]
2.5e-05
2e-05
1.5e-05
1e-05
5e-06
0
0
1
2
3
4
5
6
7

# Strategy: 1) Optimize slice emittances at the gun exit



# Strategy: 2) Find optimization start point from integrating the envelope differential equation for selected slices




$$\sigma'' + \frac{\gamma'}{2\beta^2\gamma}\sigma' + \frac{\gamma''}{2\beta^2\gamma}\sigma + \left(\frac{q\cdot B}{2mc\beta\gamma}\right)^2\sigma - \left(\frac{p_\theta}{mc\beta\gamma}\right)^2\frac{1}{\sigma^3} - \frac{\varepsilon_n}{\sigma^3} - \frac{I}{2I_0\beta^3\gamma^3\sigma} = 0$$

## Strategy: 3) Running the optimizer

- Optimizer works with any tracking code that allows comment lines in the input file:

```
! @var 0 10  -50 +100
! @goal emit4d 1 0
drift   $0   45 ….
cell 10 10 1 $p0 $p1 25 ….
```

- Optimizer dead-recons the phase shift of cavities from upstream drift length changes
- Variables are constrained: No negative drift length
- Optimizer allows multi-objectives: The emittance is optimized in at least two places in the linac to avoid an “emittance waist” at the observation point.

# Optimizing Methods

- Optimizing Problem
  - Function evaluation is expensive
  - Function evaluation is noisy
- Methods investigated
  - Simplex (Numerical Recipes)
  - Genetic algorithms (PISA, ETH Zürich)
  - Powell method (Numerical Recipes)
  - CONDOR: Constrained Optimization of Noisy Derivative-free multi-Objective high computing load functions (vanden Bergen, U. Libre de Bruxelles)

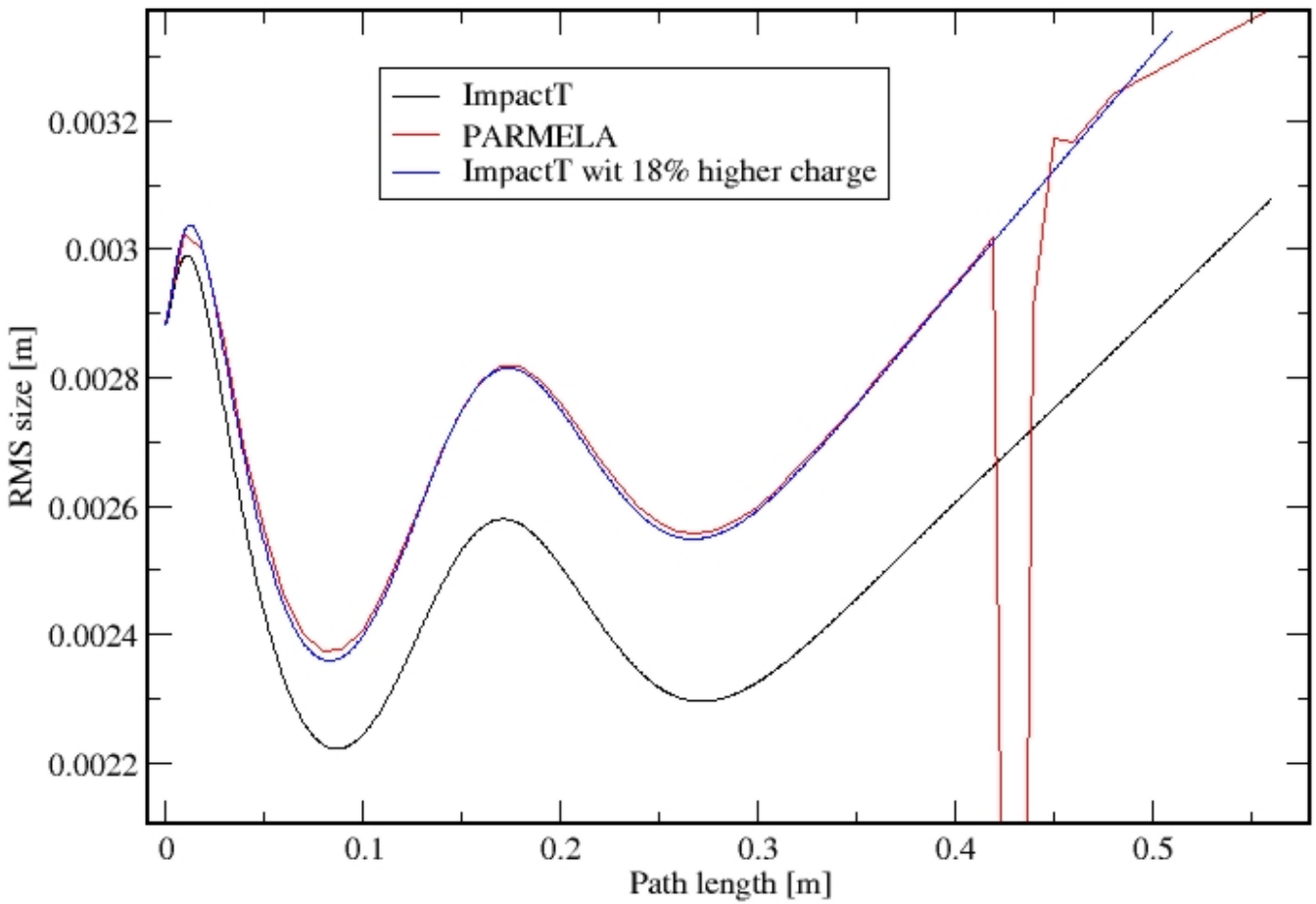
# Condor Method

- Define a “trust region” in which the function can be approximated as a quadratic polynomial.
- Calculate this polynomial from ½(n+1)(n+2) function evaluations (Multivariate Lagrange Interpolation).
- Optimize the function value, using all new evaluations to update the polynomial.

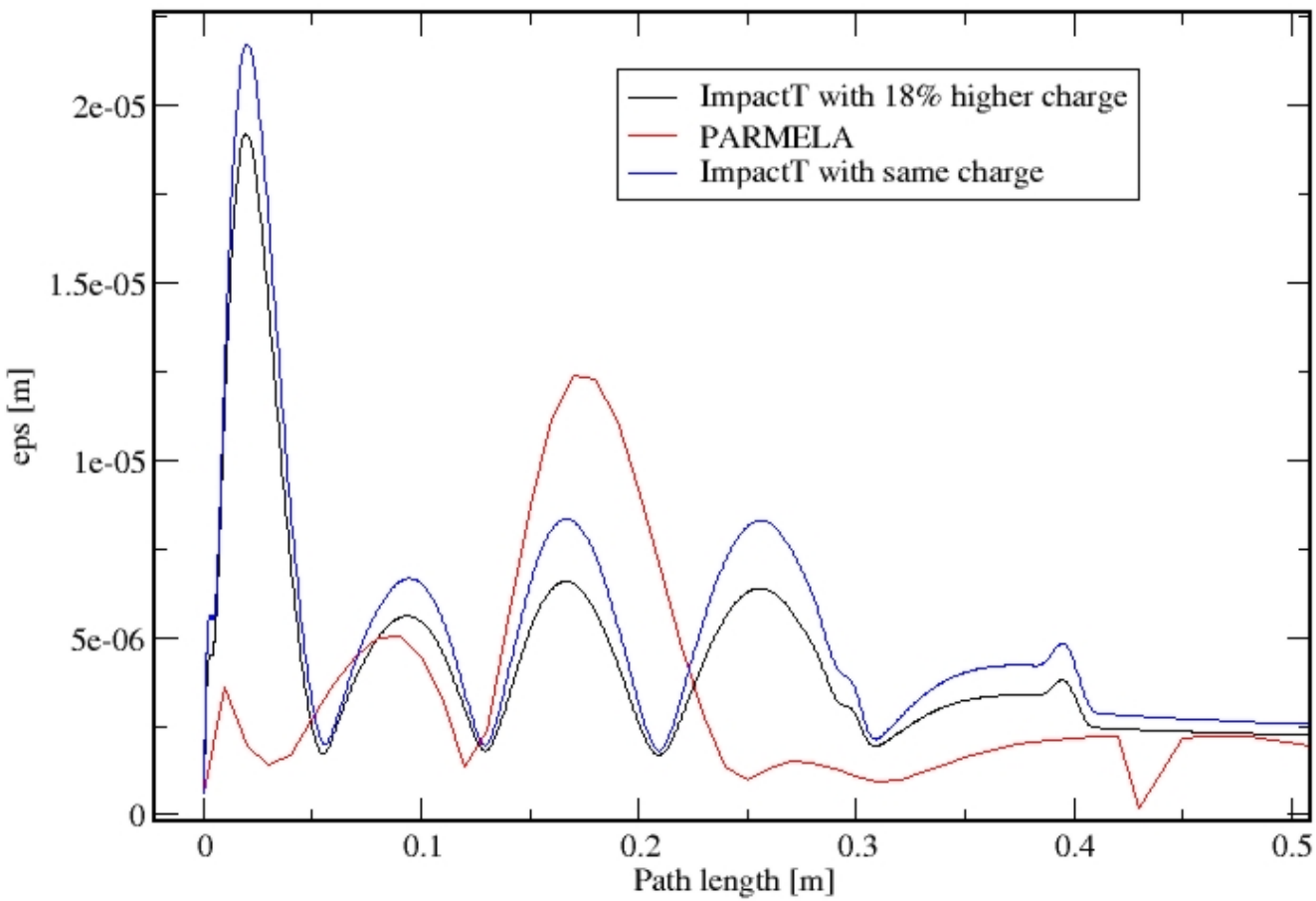
# How to avoid local minima

- Simplex extension: Simulated annealing
  - Robust, but needs many function evaluations.
- Genetic algorithms
  - Sufficiently large initial population required
- Condor: Use multiple start points
  - Common data base of function values used for the polynomial generation.
  - Parallel version commercially available.

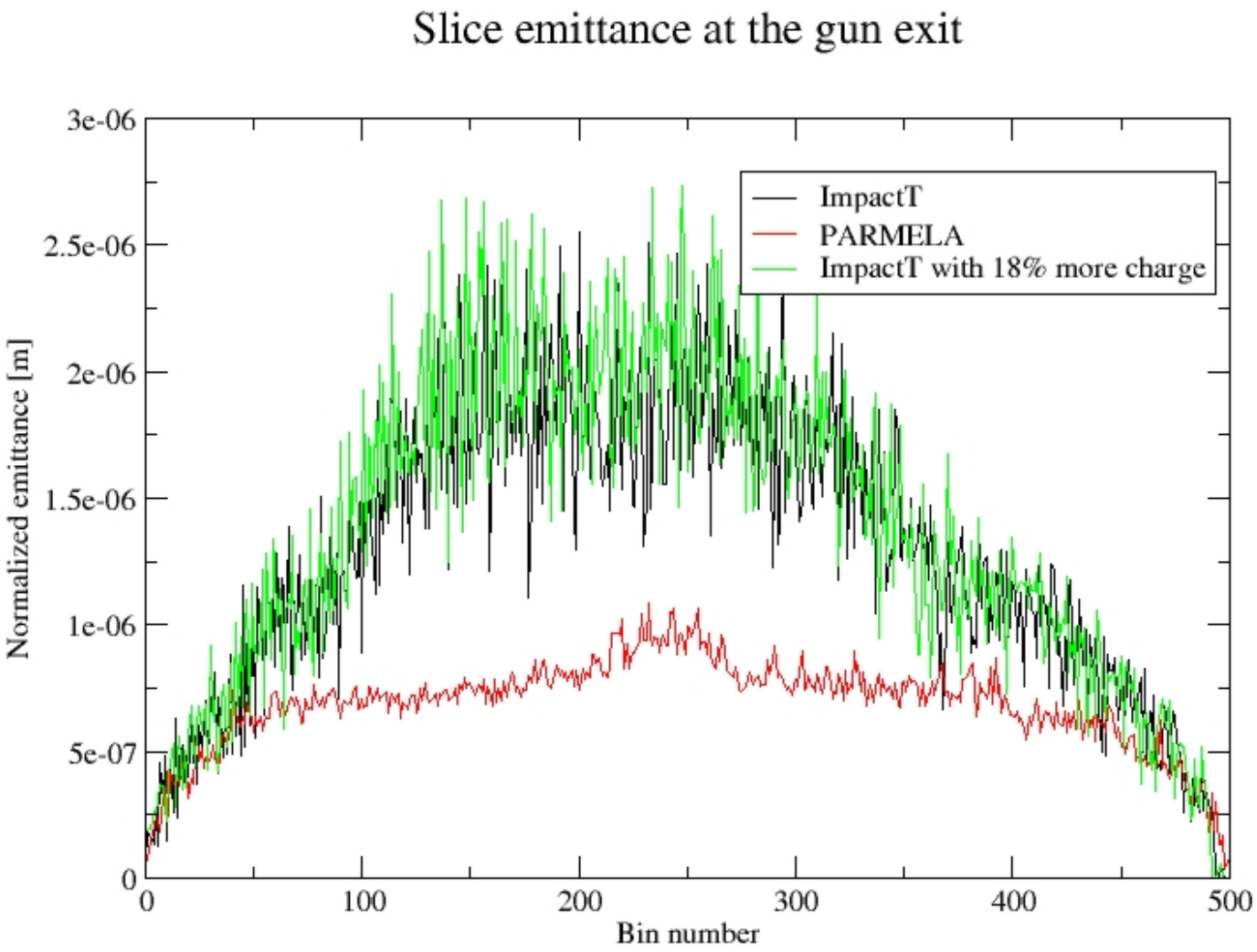
# Comparison PARMELA - ImpactT



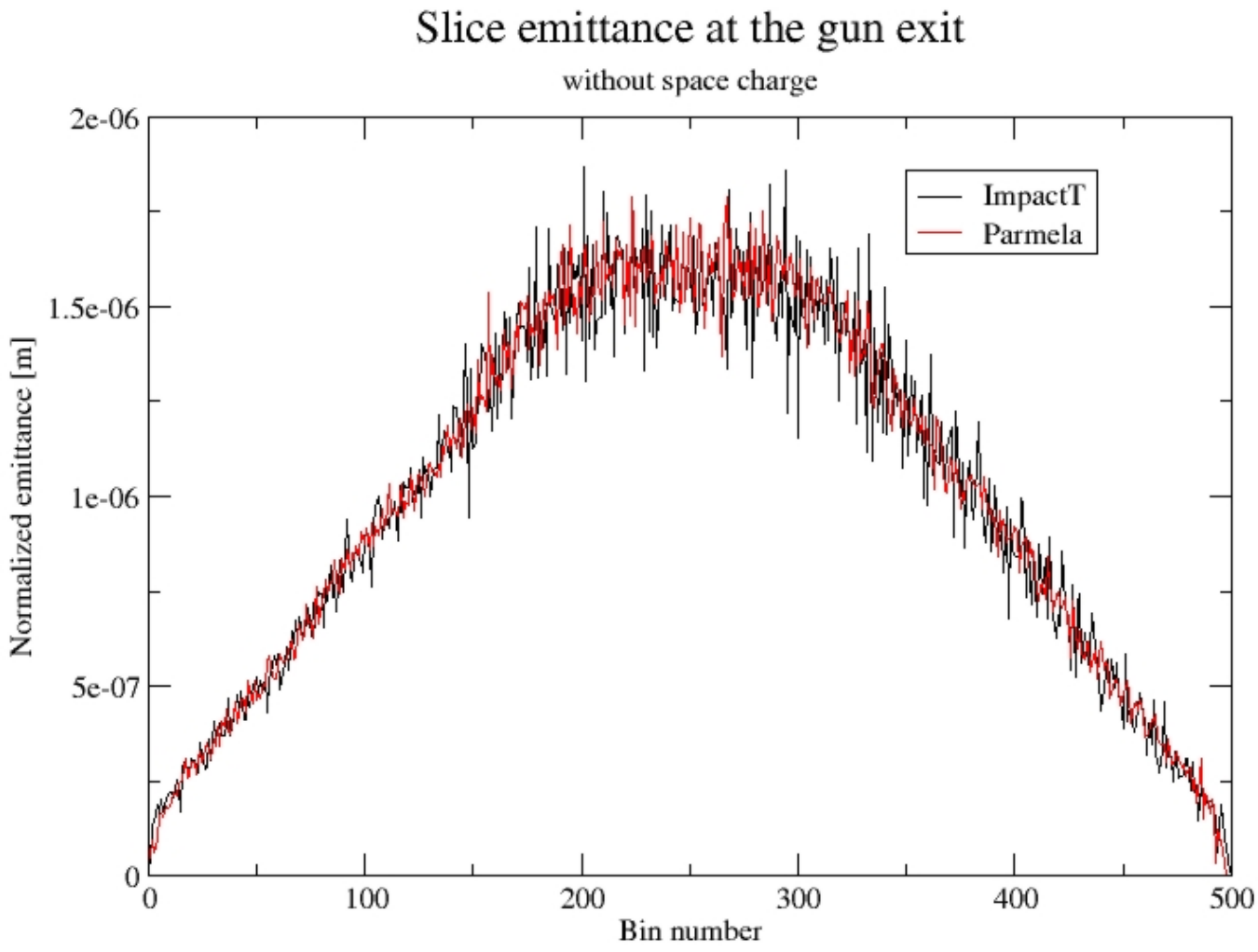
# Comparison Parmela - ImpactT



# Comparison PARMELA - ImpactT



# Comparison PARMELA -ImpactT



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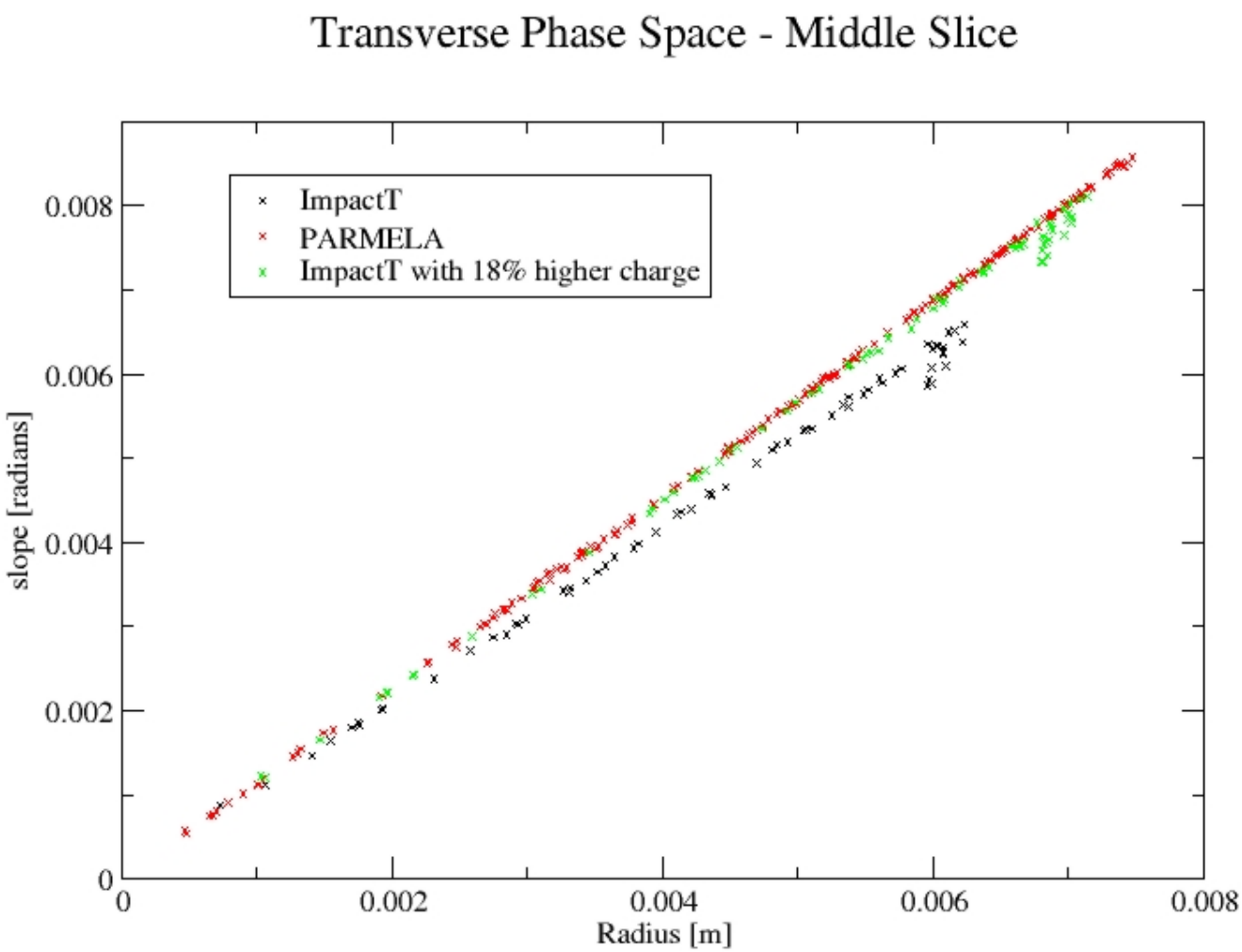

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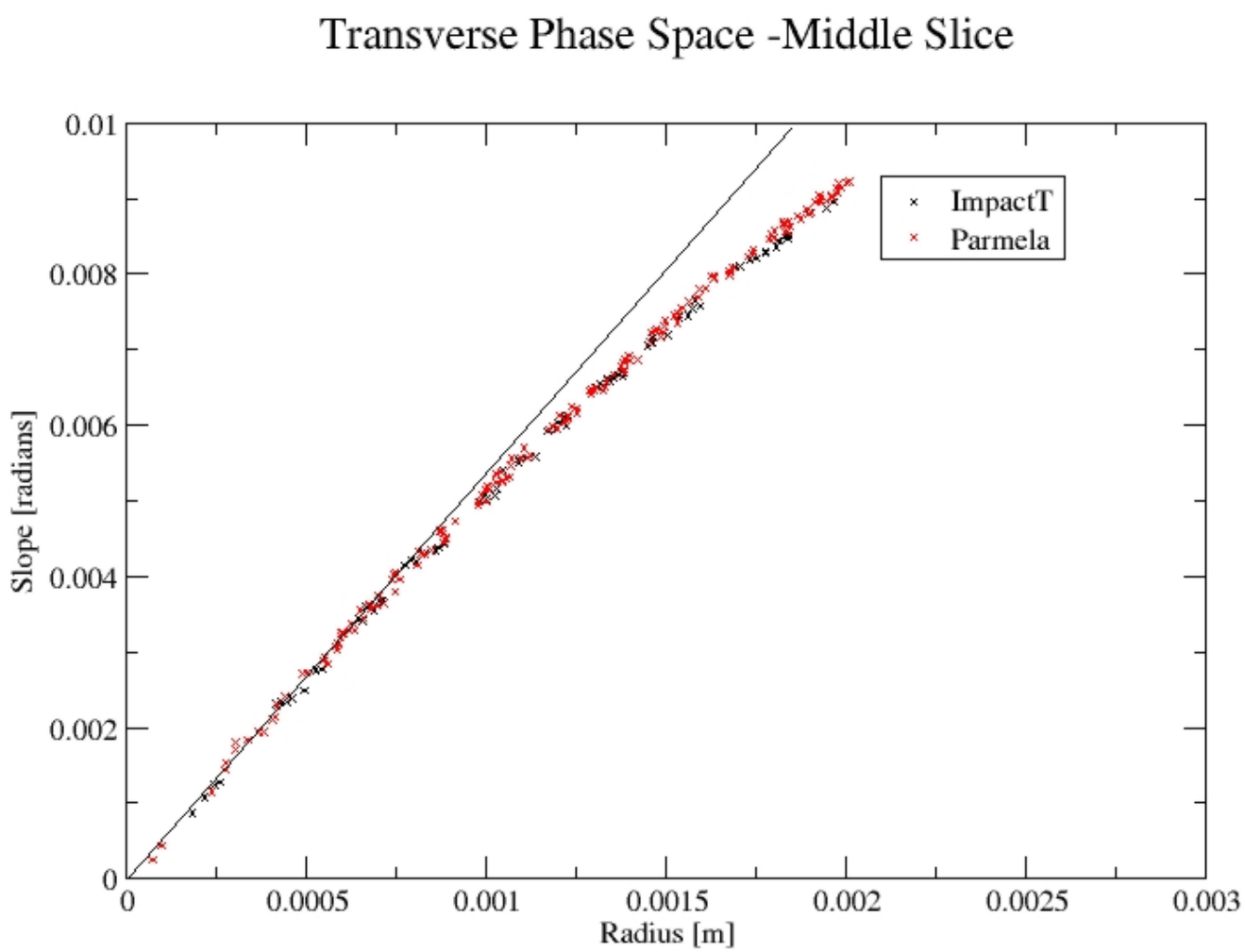
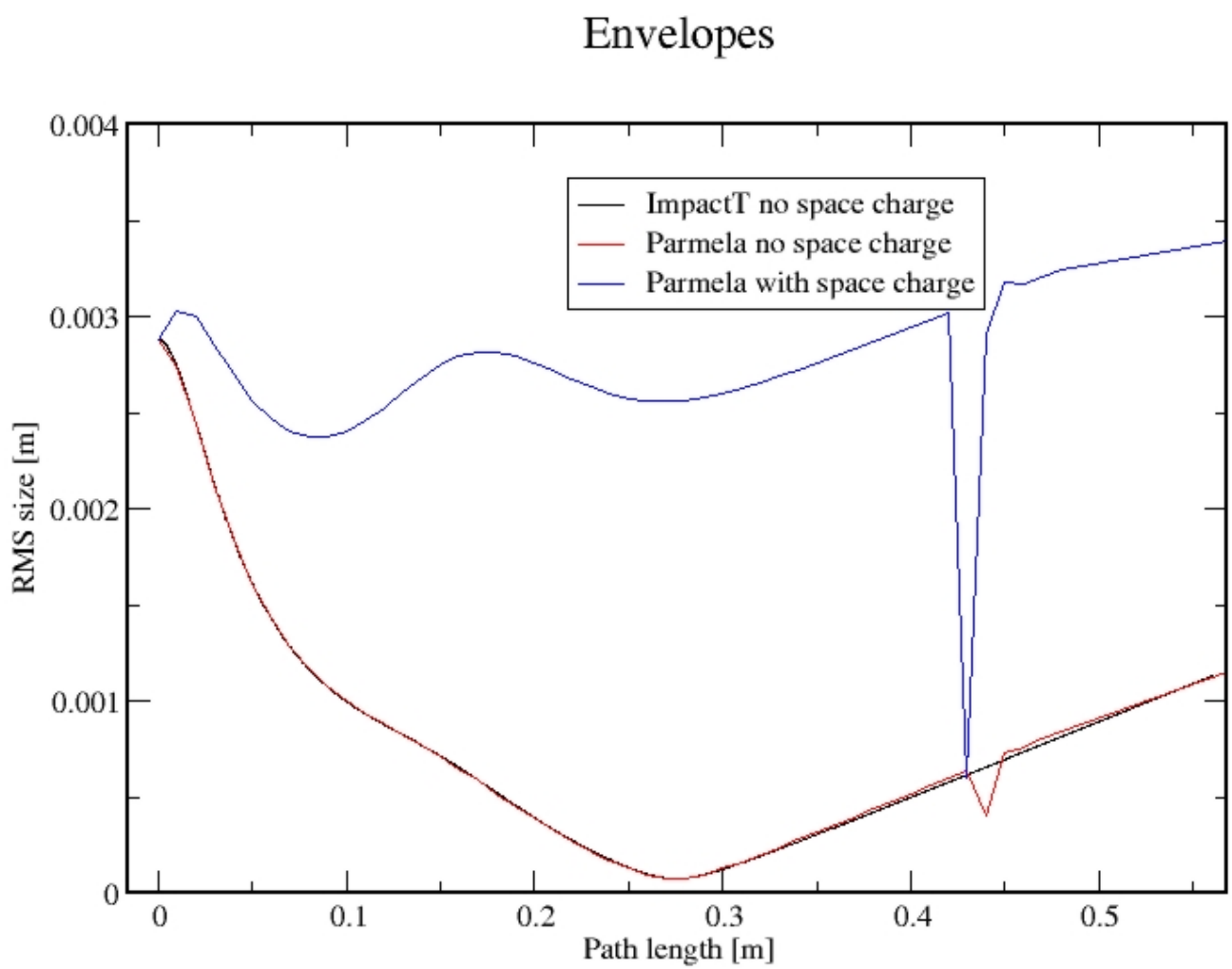
# Comparison PARMELA -ImpactT