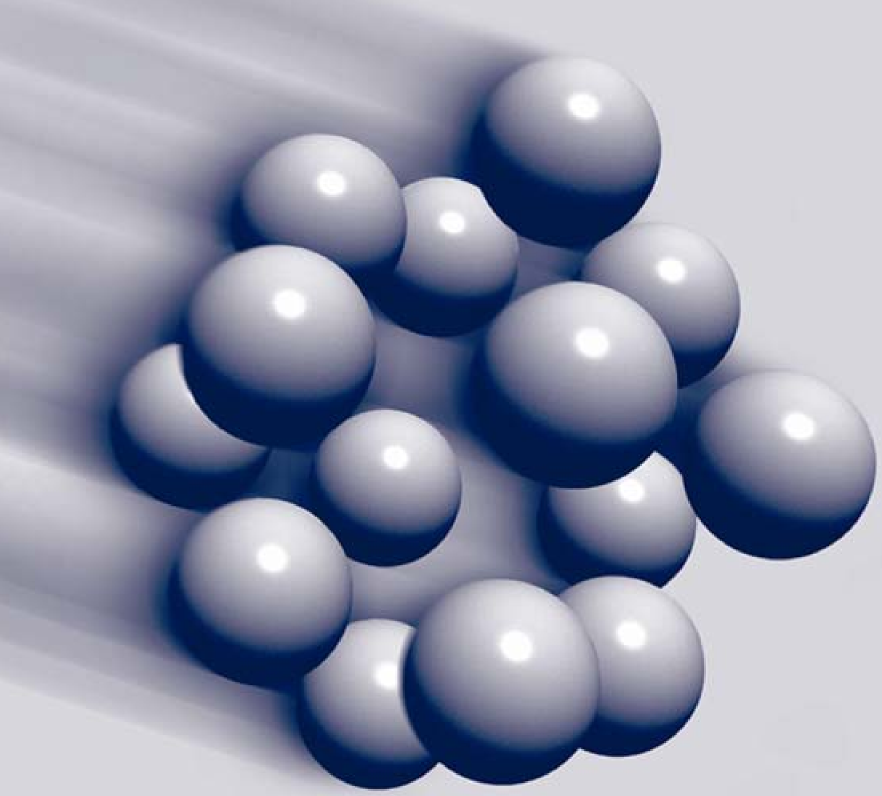
The General Particle Tracer (GPT) code applied to the PITZ benchmark problem



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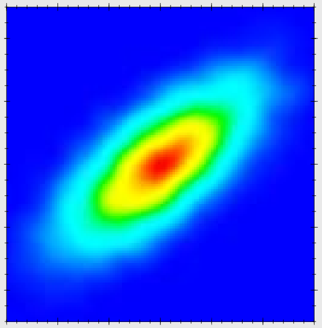
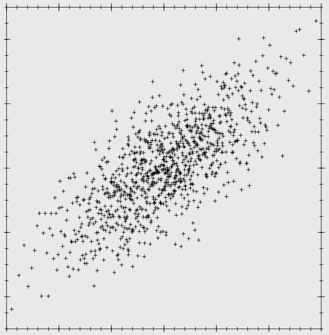
Equations of motion

- GPT tracks sample particles in time-domain
- Relativistic equations of motion

$$\frac{d\,\mathbf{p}}{dt} = q \cdot \left(\mathbf{E} + \frac{d\mathbf{r}}{dt} \times \mathbf{B} \right)$$

$$\frac{d\,\mathbf{r}}{dt} = \frac{c\,\mathbf{p}}{\sqrt{m^2 c^2 + \mathbf{p} \cdot \mathbf{p}}}$$





- Solved with 5th order embedded Runge Kutta, adaptive stepsize
- GPT can track ~10^6 particles on a PC with 1 GB memory

- Challenges:
  - **E**(**r**,t), **B**(**r**,t)
  - Initial particle distribution

Initial particle distribution

GPT allows full flexibility in 7D (position, momentum, release time)

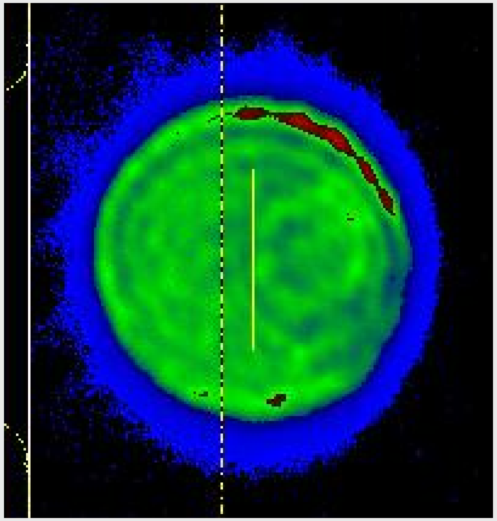
- Uniform, Gaussian, Linear, etc. etc., distributions

Implemented by over 30 elements

- Hammersley sequences and/or random

This benchmark

- Time: Uniform convoluted with gaussian
- Momentum: Isotropic 'half-sphere' 0.5 eV
- Position: Laser-profile from image



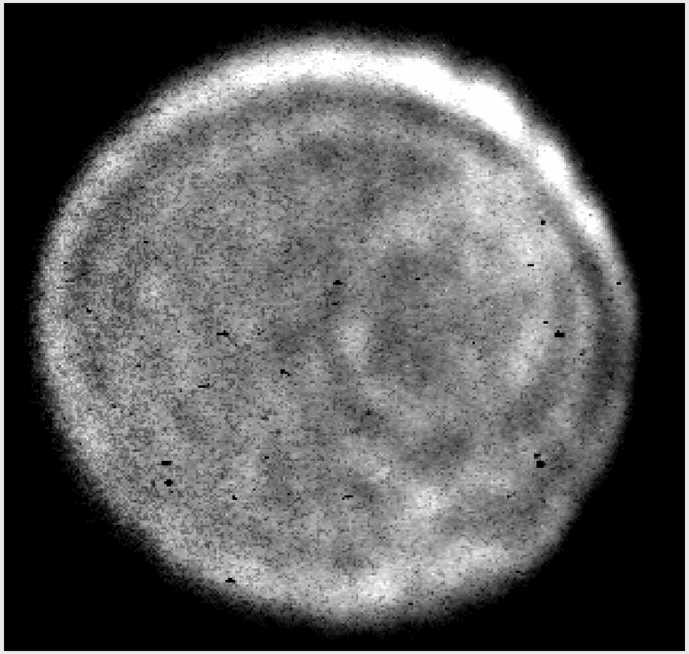
PITZ false-color laser profile

Laser profile from image

- GPT can read laser-image files in .bmp format

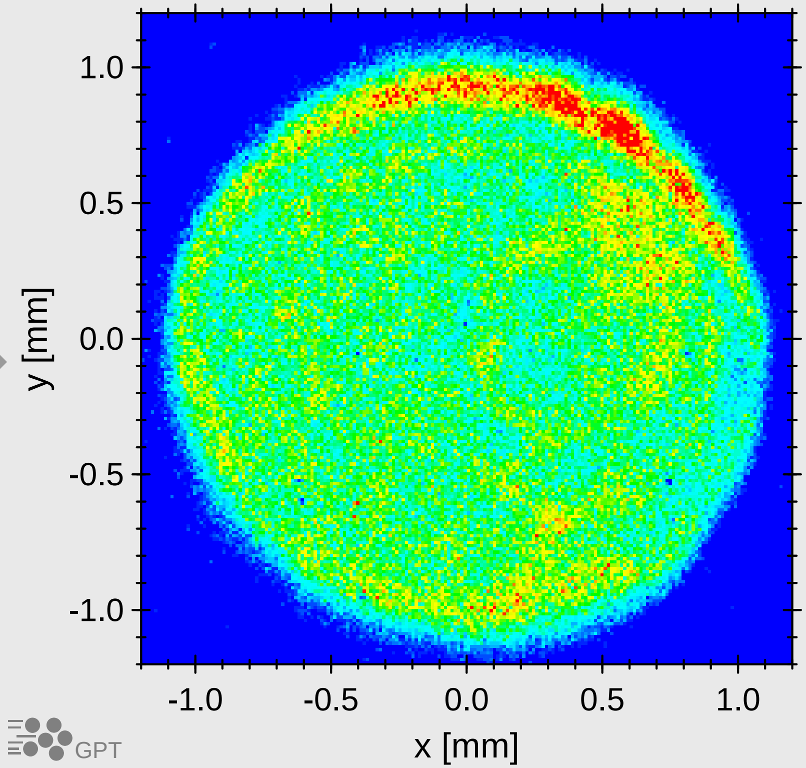
```
setxydistbmp("image-file.bmp",[1/pixel-size])
```

PITZ grayscale .tif image



Xrms=0.54 mm, Yrms=0.57 mm

GPT initial particle distribution



Std(x) = 0.542079 mm   Std(y) = 0.563787 mm

Electromagnetic fields

- External fields
  - Built-in (analytical) elements
  - **Field-maps**
  - User-defined expressions

- Space-charge
  - 2D/3D point-to-point
  - **Multigrid Poisson (PIC)**

- Radiation
  - FEL interaction
  - (Coherent) Synchrotron Radiation
  - Wakefields

Field-maps

- 1D, 2D, 3D
- Rely on external solvers
- Fields are summed
- 3D positioning, 3D orientation

Example: Strathclyde rf-photo gun

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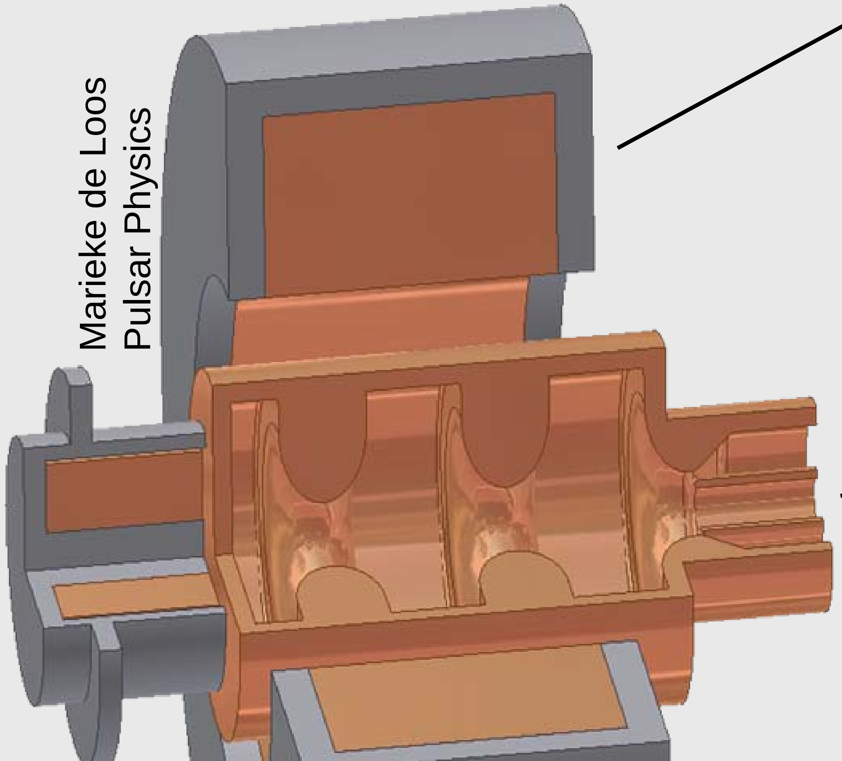
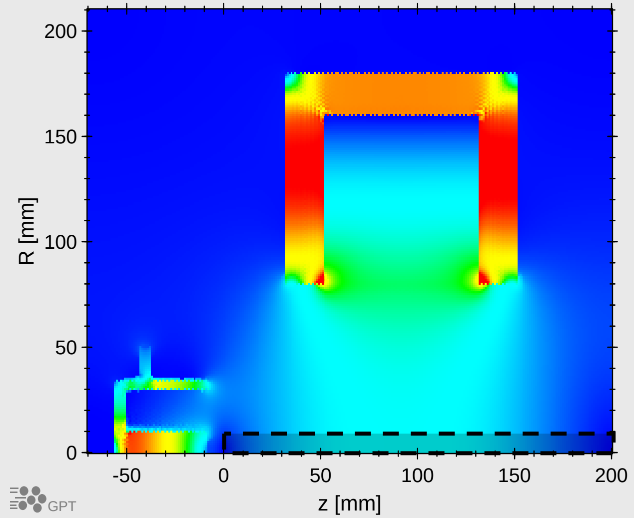
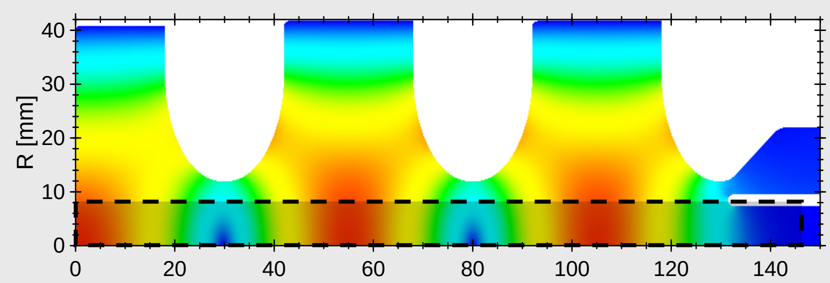


Magnet

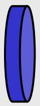


Cavity



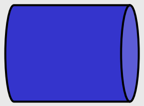
Only this part is fed into GPT

Space-charge (3D mesh)



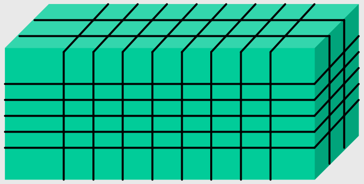
Bunch in laboratory frame

- <u>Mesh-based electrostatic solver in rest-frame</u>



Bunch in rest frame

- Bunch is tracked in laboratory frame
- Calculations in rest-frame $z' \approx \gamma\, z,\ \gamma = 1\Big/\sqrt{1 - v^2/c^2}$



Meshlines

- Mesh
  - Density follows beam density
  - Trilinear interpolation to obtain charge density

ρ'

Charge density

$-\nabla^2 V' = \rho'/\varepsilon_0$

Poisson equation

- Solve poisson equation

$\mathbf{E}' = -\nabla V' \quad \mathbf{B}' = 0$

Interpolation

- 2nd order interpolation for the electrostatic field **E'**

$\{\mathbf{E},\mathbf{B}\} = \mathcal{L}(\mathbf{E}')$

Lorentz transformation to laboratory frame

- Transform **E'** to **E** and **B** in laboratory frame

Multi-grid Poisson solver

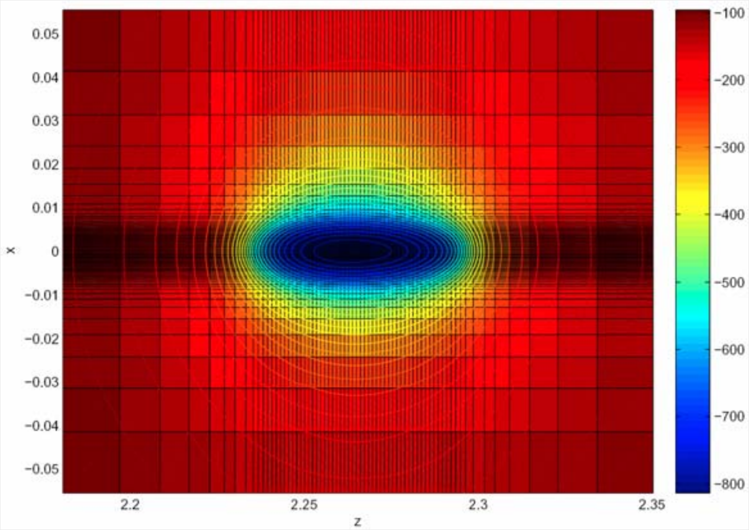
- Key feature:
  - Anisotropic meshing to reduce number of empty nodes

- Main challenge
  - Stability

- Multi-grid solver
  - Developed by Dr. G. Pöplau
    Rostock University, Germany
  - Scales ~O(N^1) in CPU time
  - Select stability vs. speed

- Ongoing research
  - Boundary conditions
  - Meshing

DESY TTF gun at z=0.25 m, 200k particles.

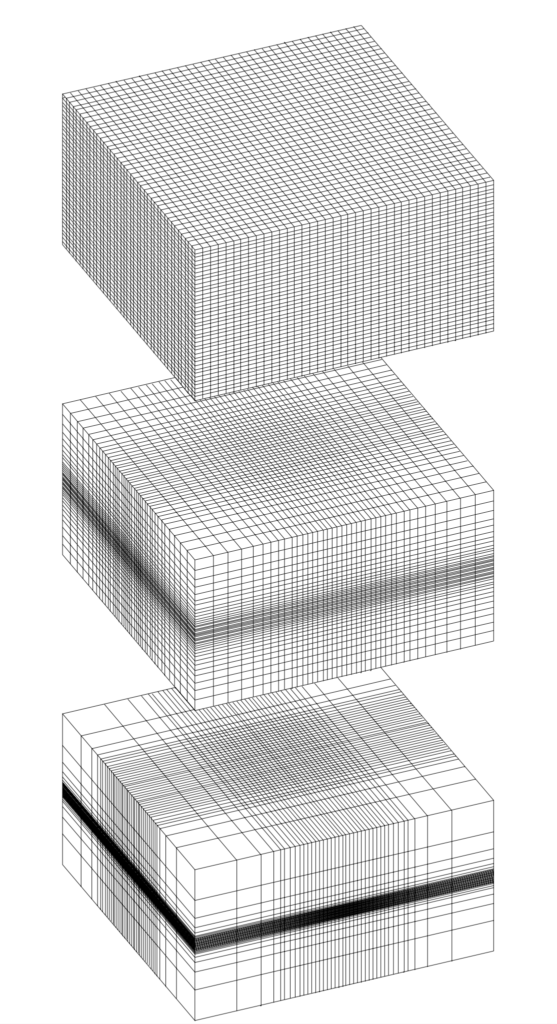


Adaptive meshing

- Reduce ‘wasted’ CPU time in empty volume
  - Meshlines follow projected beam density

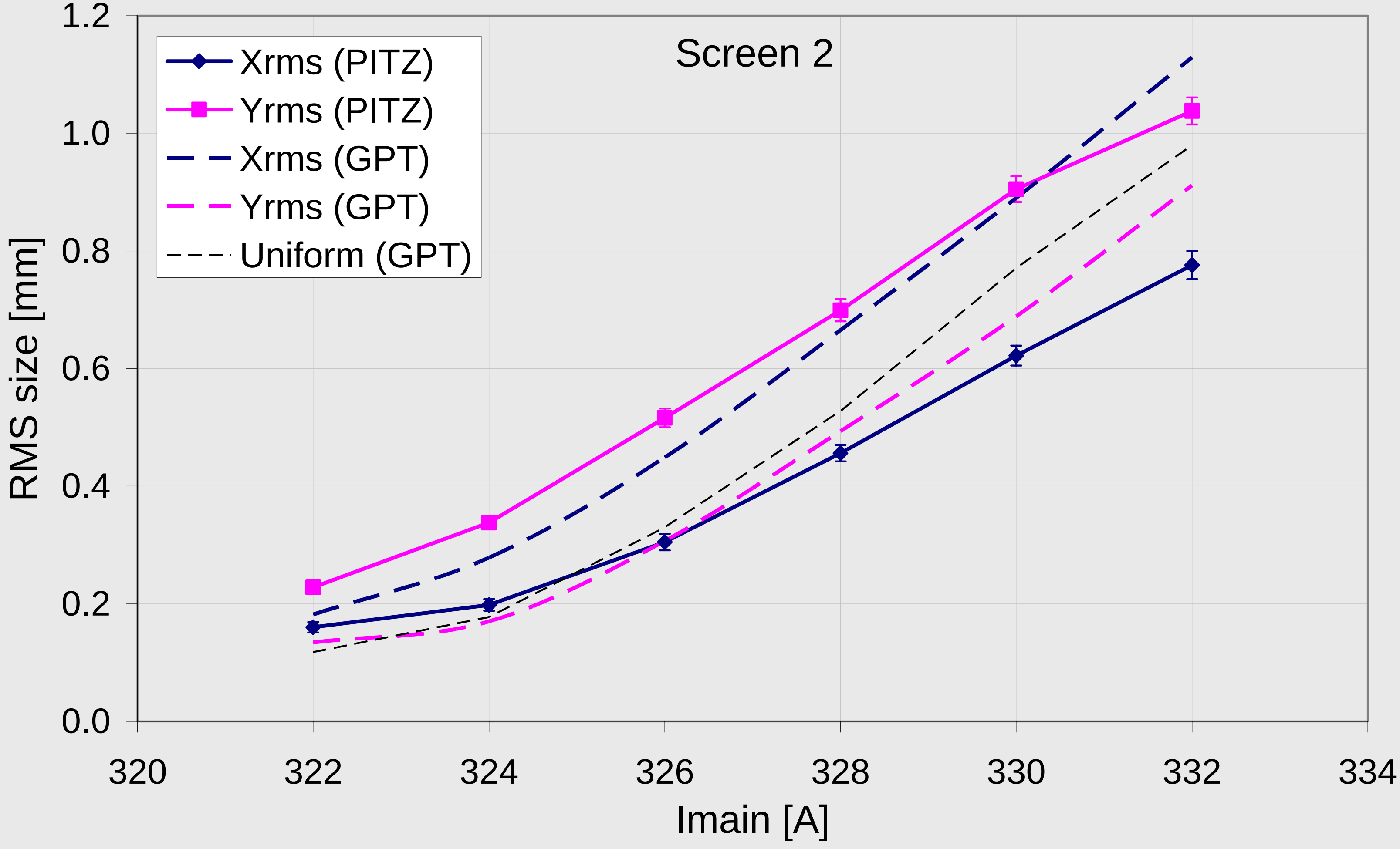
- Selectable ‘adaptiveness’ by enforcing a maximum difference between neighboring meshlines
  - Parameter to determine stability vs. speed

- Ongoing research to define optimal number of meshlines and adaptiveness as function of bunch parameters and desired final accuracy.

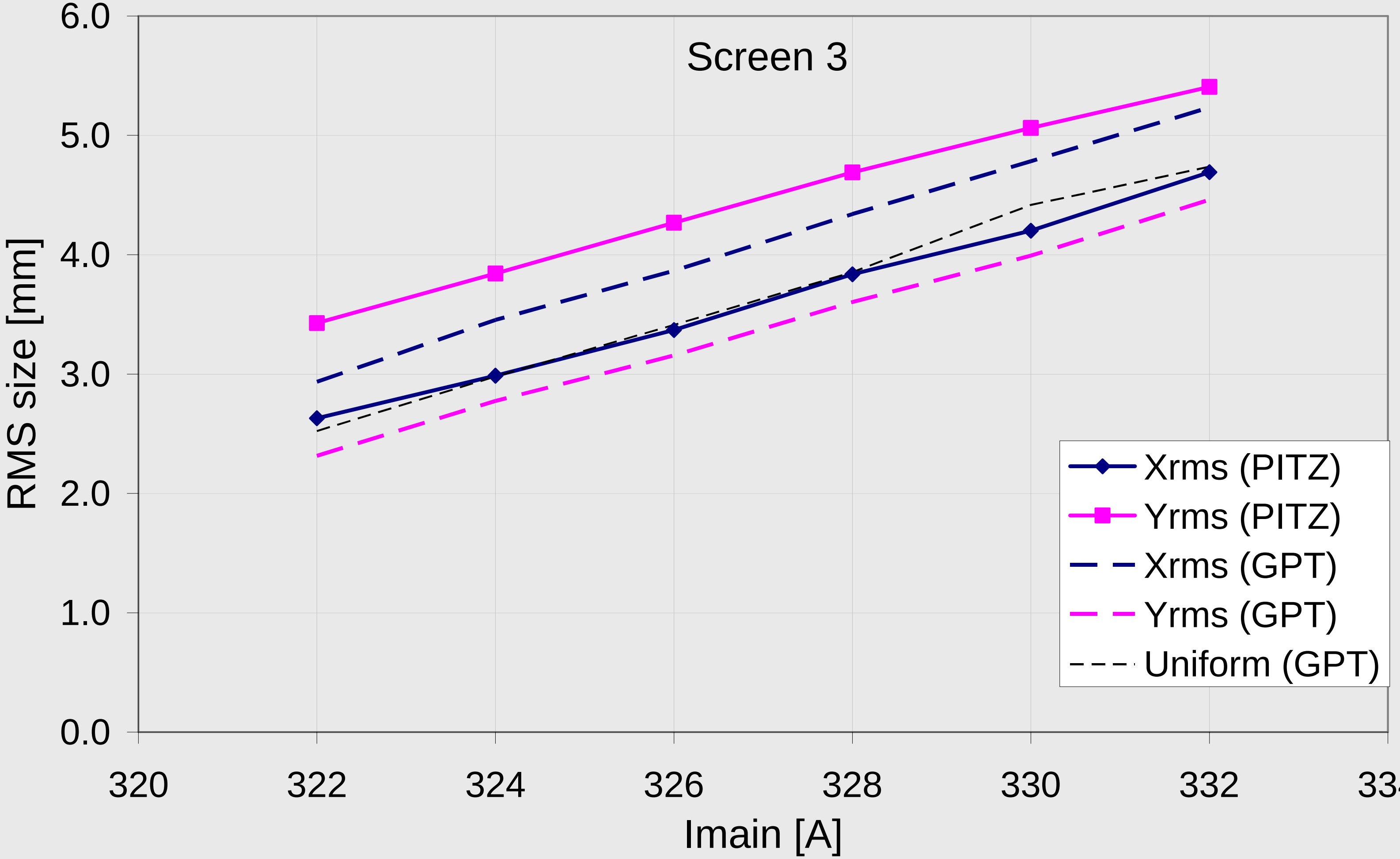


Adaptiveness of 0, 20 and 100%

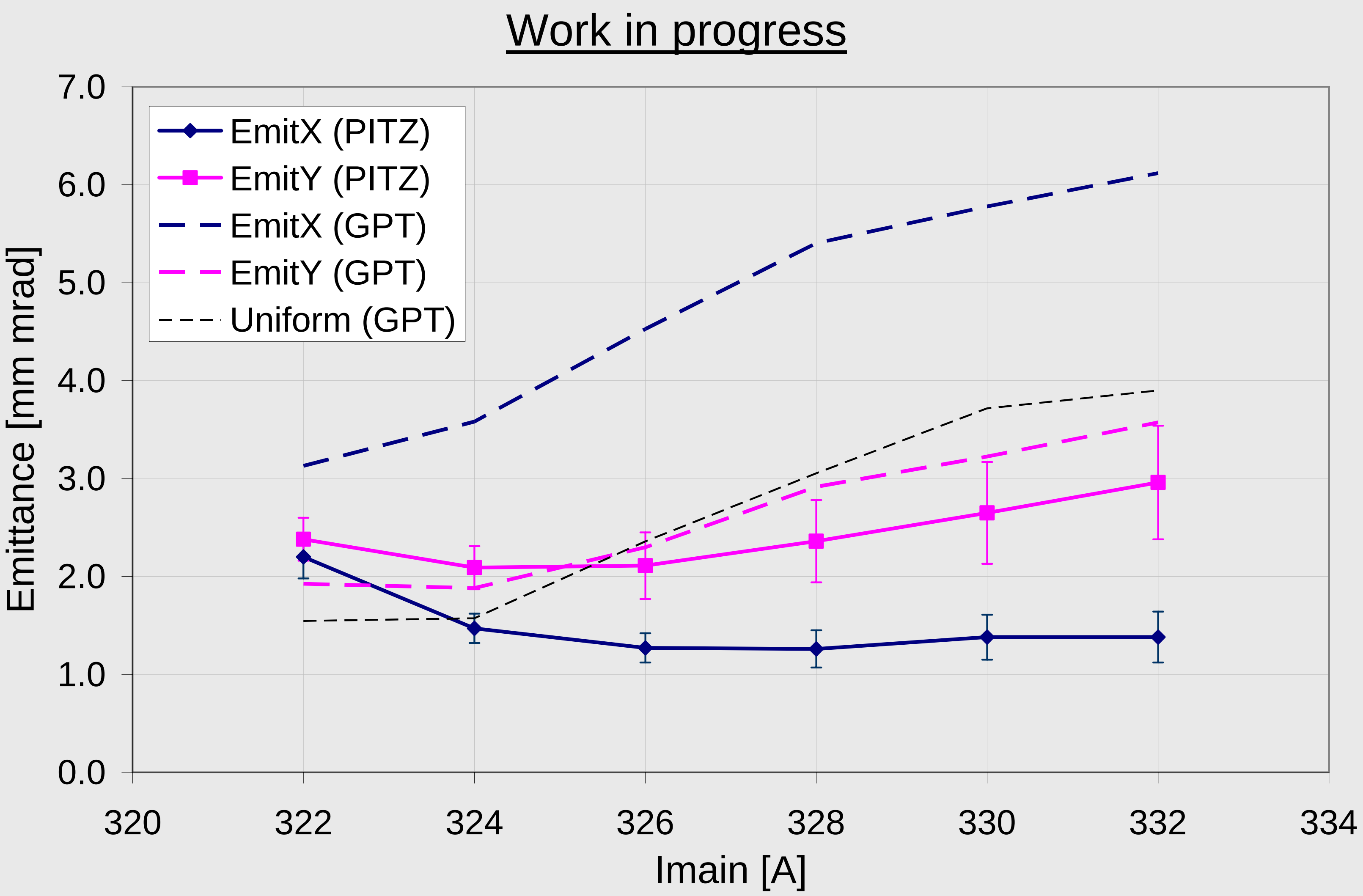
Benchmark results: Screen 2



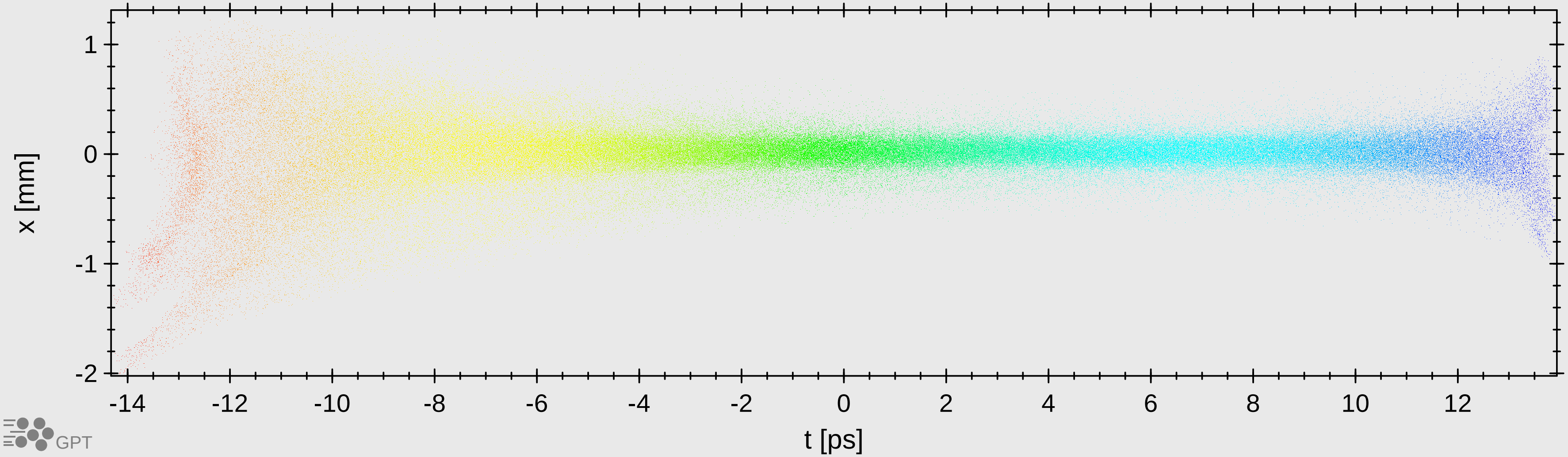
Benchmark results: Screen 3

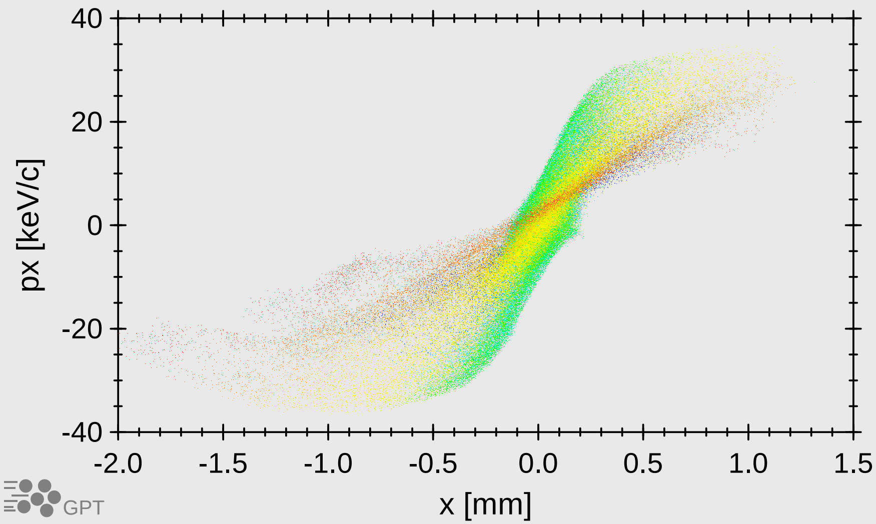


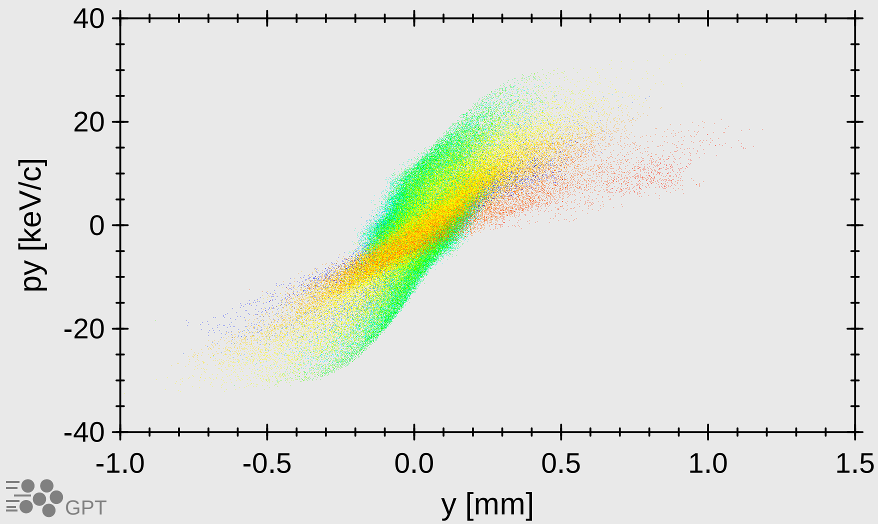
Benchmark results: Emittance



Phase-space: Screen1, Imain=324







Conclusion

Screens:

- Good agreement
- Swap X and Y?

Emittance (work in progress):

- Presented GPT simulations overestimate the emittance
  - Optimization desired: Maybe just phase-error

- ‘Slice’ effect
  - Depends strongly on head and tail of the bunch

- Emittance is significantly affected by non-uniform laser image