Simulations for the Gamma Factory proof-of-principle experiment at the SPS

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My python-based simulations:

Earlier work:

Longitudinal dynamics of a single ion and an ion bunch in the LHC/SPS + laser:
https://indico.cern.ch/event/668097/contributions/2796070/
http://www.inp.nsk.su/~petrenko/misc/ion_cooling/animations/
https://apetrenko.blob.core.windows.net/misc/Li_like_Pb_cooling.html

GF PoP Experiment:

Laser intensity estimates and Monte Carlo simulations for laser-ion bunch interaction region:
https://anaconda.org/petrenko/psi_beam_vs_laser

LHC-based Gamma Factory simulations:

https://anaconda.org/petrenko/lhc_psi_beam_vs_laser

Next steps:

+ multiple photon absorption/emission (for LHC Gamma-Factory),
+ realistic laser parameters,
+ parallelization
+ release code as a python library
+ collective effects via longitudinal and transverse impedance
+ intra-beam scattering/stripping
+ …?

Monte Carlo scheme:

1) Define the ion beam

```
X = np.matrix([
  x ,
  xp,
  y ,
  yp,
  z ,
  dp
])
```

2) Define the 1-turn transformation (matrix + RF-cavity as a function)

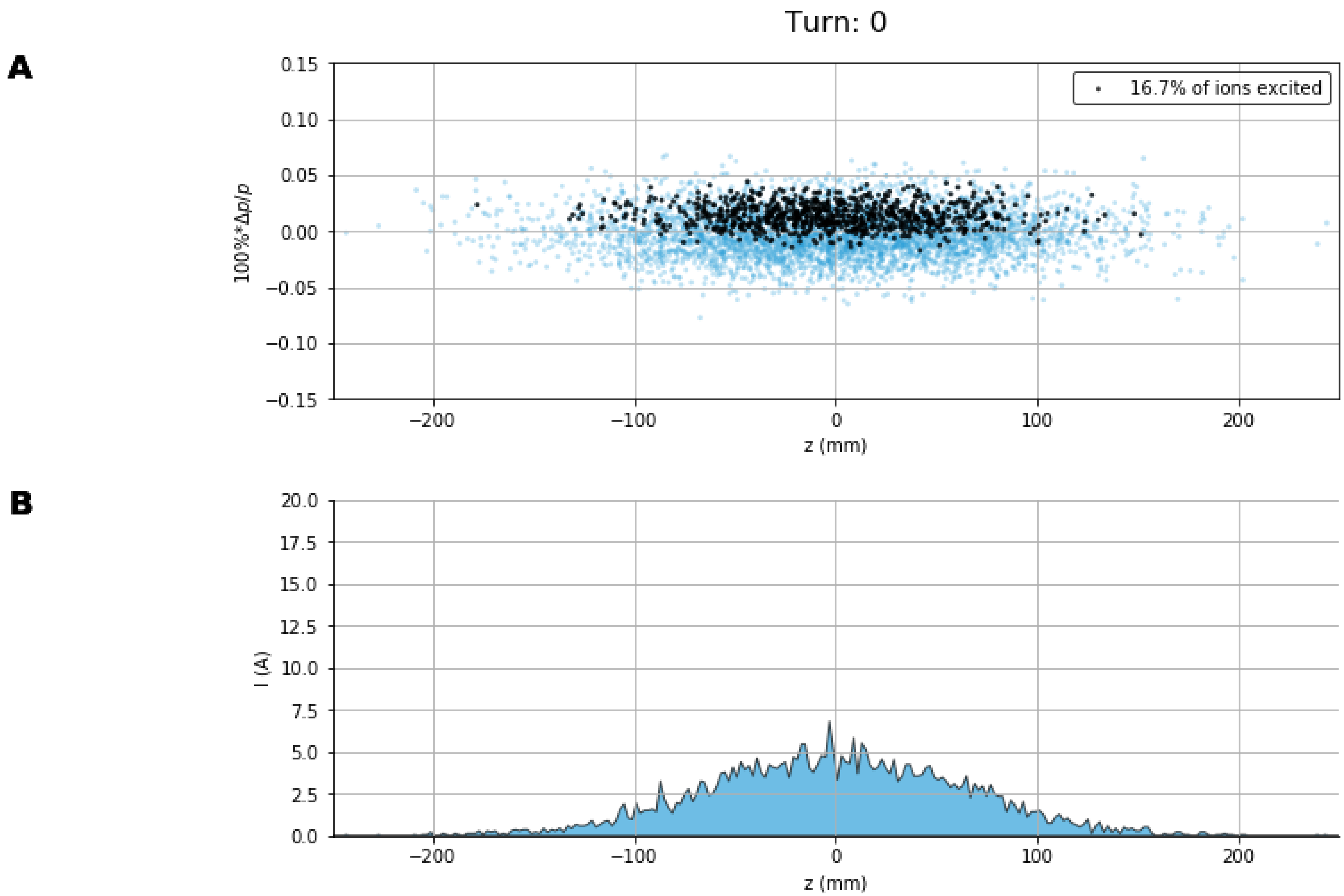
```
M = np.matrix([
    [ R11,  R12, 0  , 0  ,  0  ,  R16],
    [ R21,  R22, 0  , 0  ,  0  ,  R26],
    [ 0  ,  0  , R33, R34,  0  ,  0  ],
    [ 0  ,  0  , R43, R44,  0  ,  0  ],
    [-R51, -R52, 0  , 0  ,  1  , -R56+L/(gamma_0*gamma_0)],
    [ 0  ,  0  , 0  , 0  ,  0  ,  1  ]
])
```

3) Define laser beam

Then turn-by turn simulation is defined in a simple loop:

```
for turn in range(0,100000):
    Excited = ExciteIons(X)          # ion excitations
    X = EmitPhotons(X, Excited)      # photon emissions
    X = RFcavity(X, h, eVrf, phi0) # beam goes through RF-cavity
    X = M*X                          # 1-turn matrix
```

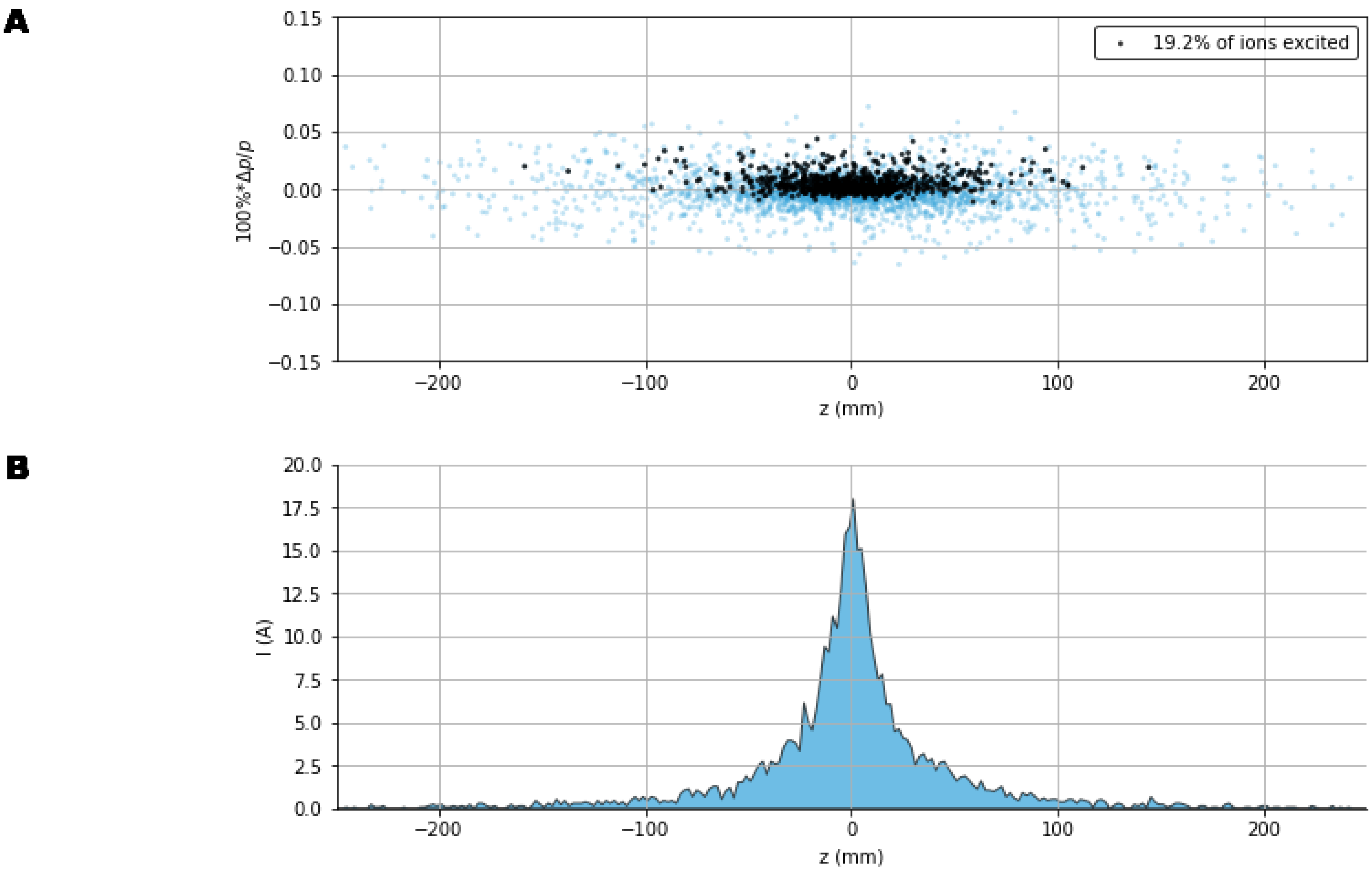
SPS PoP Experiment Cooling
2.6 degrees crossing angle, 5 mJ laser, σ(Δp/p)=2e-4:



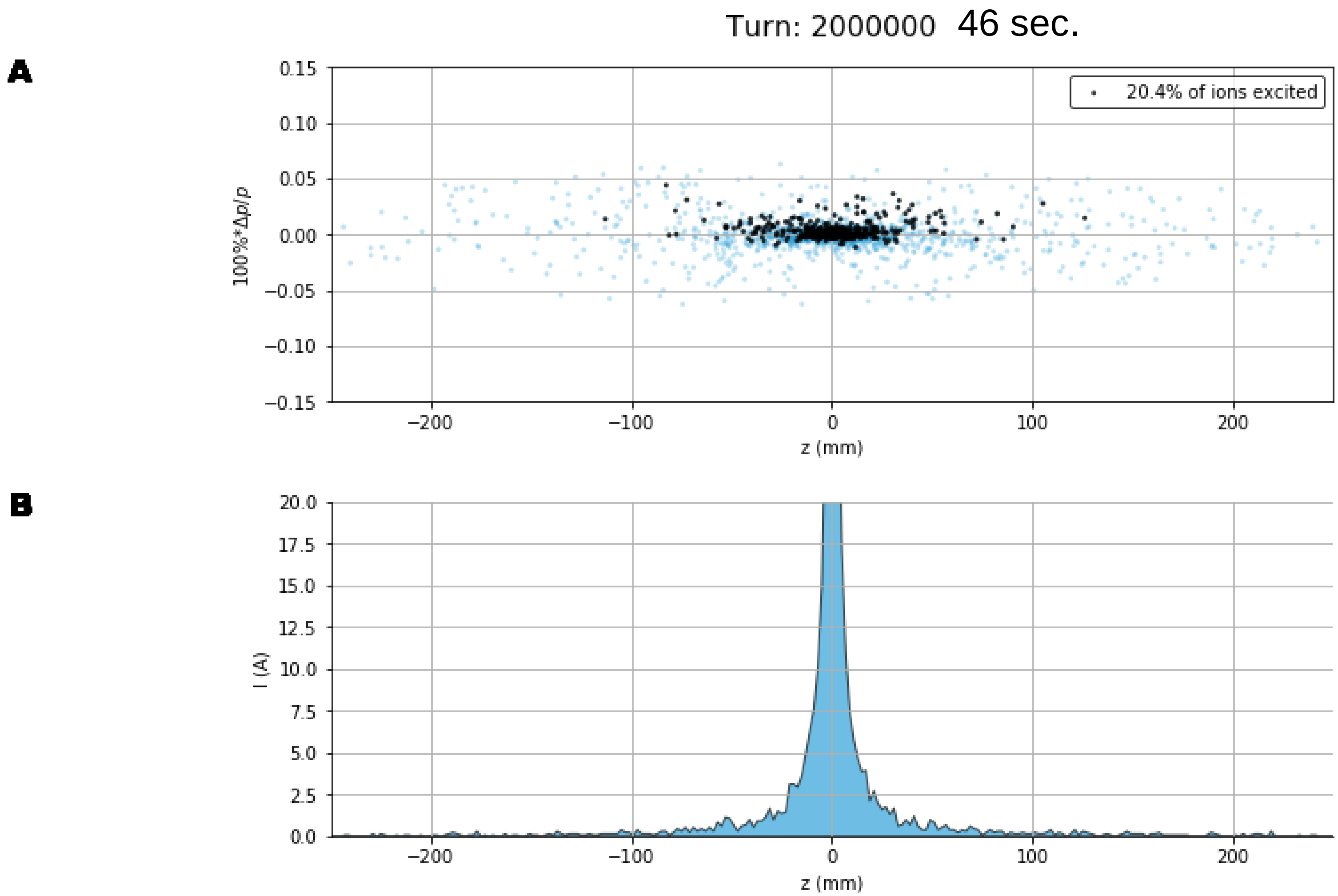
Parameter table for the SPS PoP experiment:
https://espace.cern.ch/PBC-acc-GammaFactory/default.aspx

SPS PoP Experiment Cooling
2.6 degrees crossing angle, 5 mJ laser, σ(Δp/p)=2e-4:

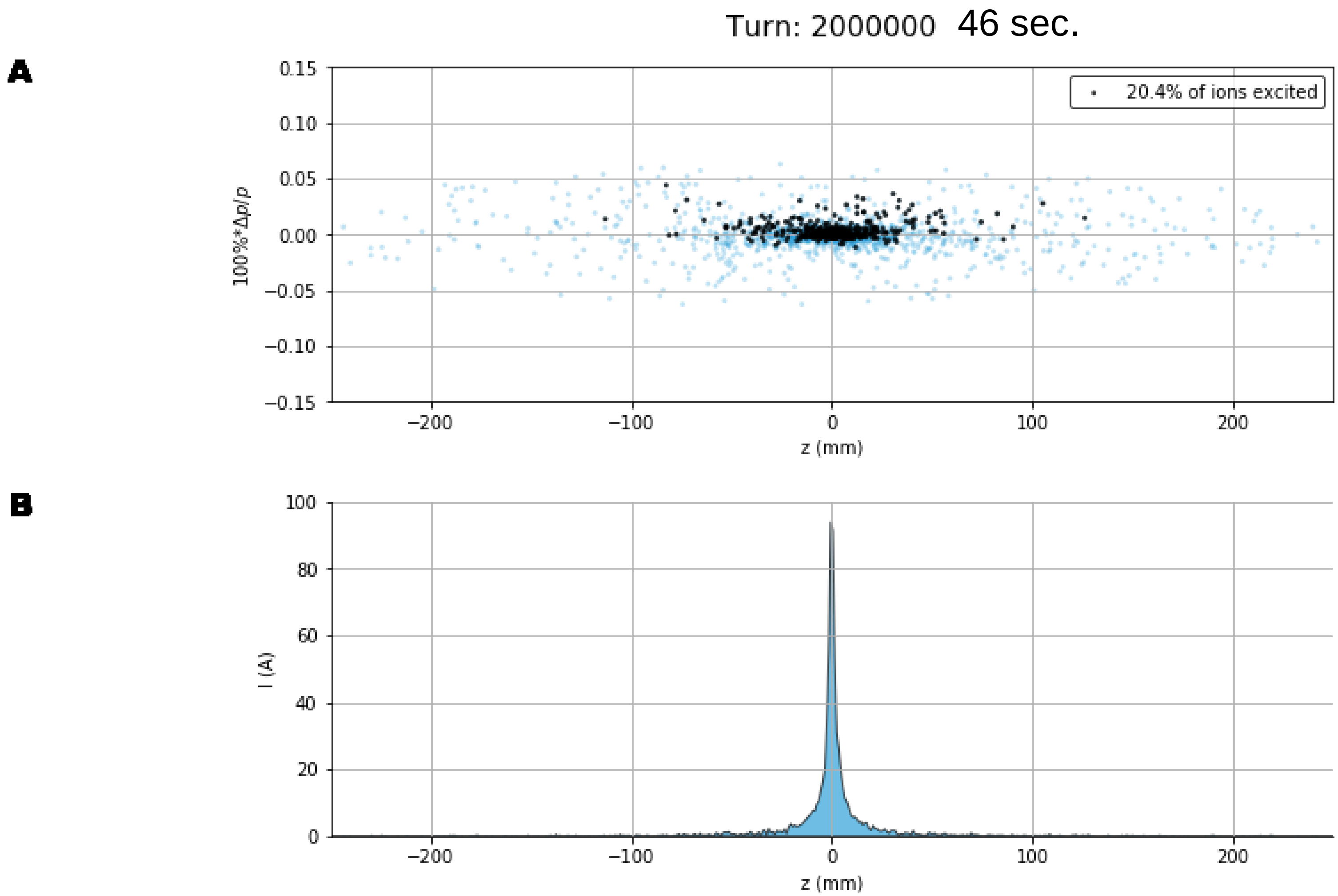
Turn: 1000000 23 sec.



SPS PoP Experiment Cooling
2.6 degrees crossing angle, 5 mJ laser, σ(Δp/p)=2e-4:

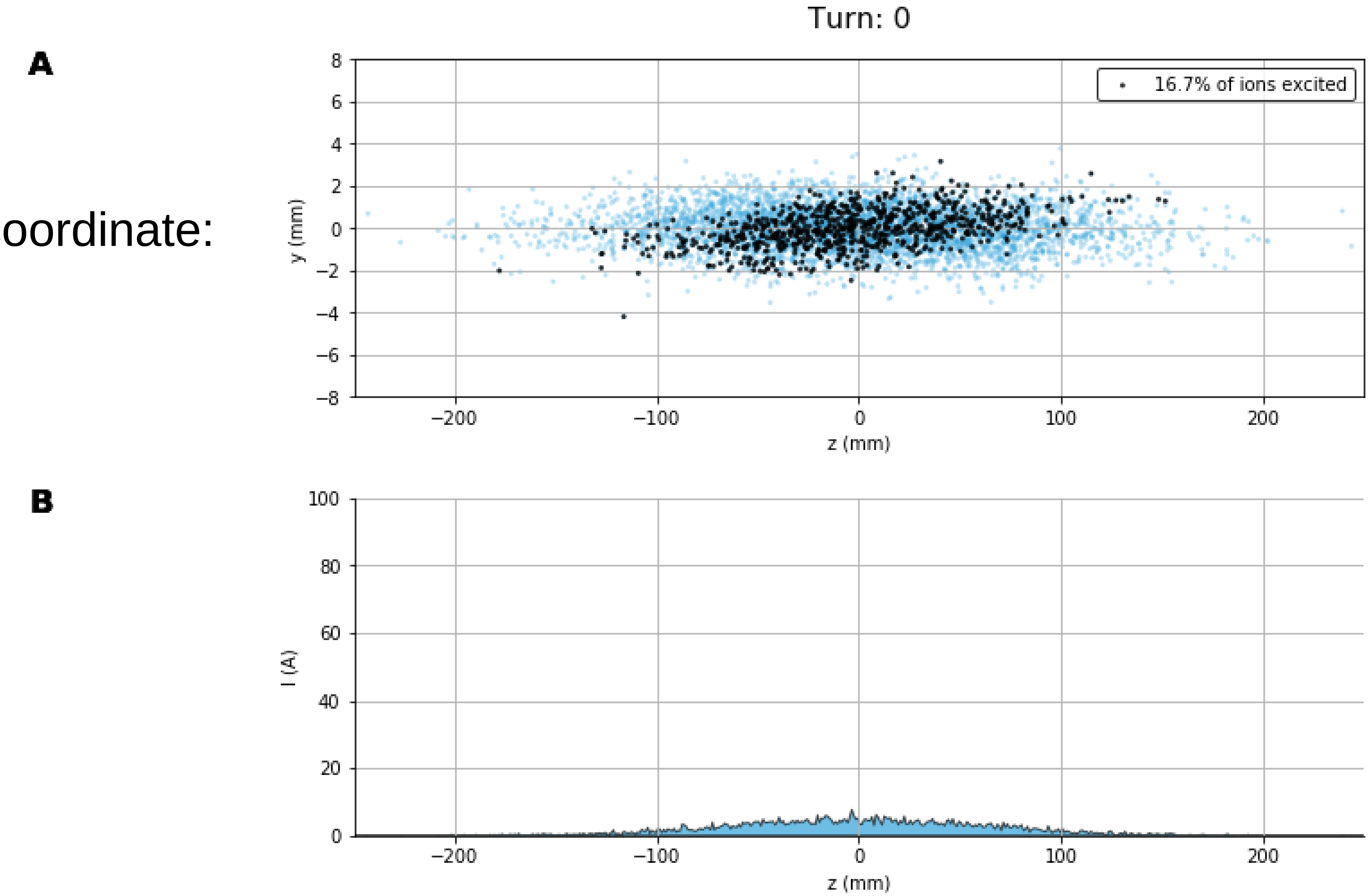


SPS PoP Experiment Cooling
2.6 degrees crossing angle, 5 mJ laser, σ(Δp/p)=2e-4:



SPS PoP Experiment Cooling
2.6 degrees crossing angle, 5 mJ laser, σ(Δp/p)=2e-4:

Vertical coordinate:



SPS PoP Experiment Cooling
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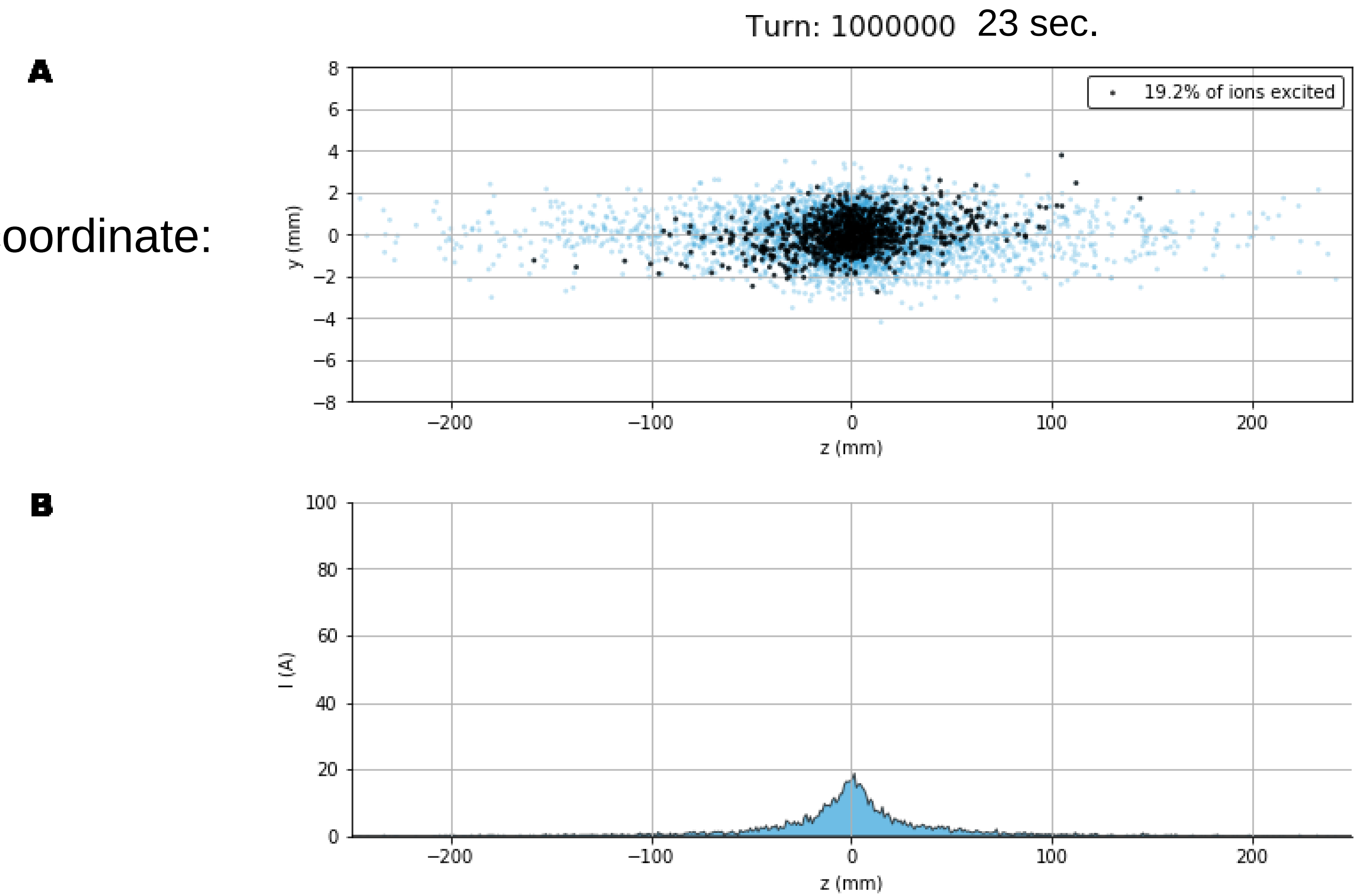
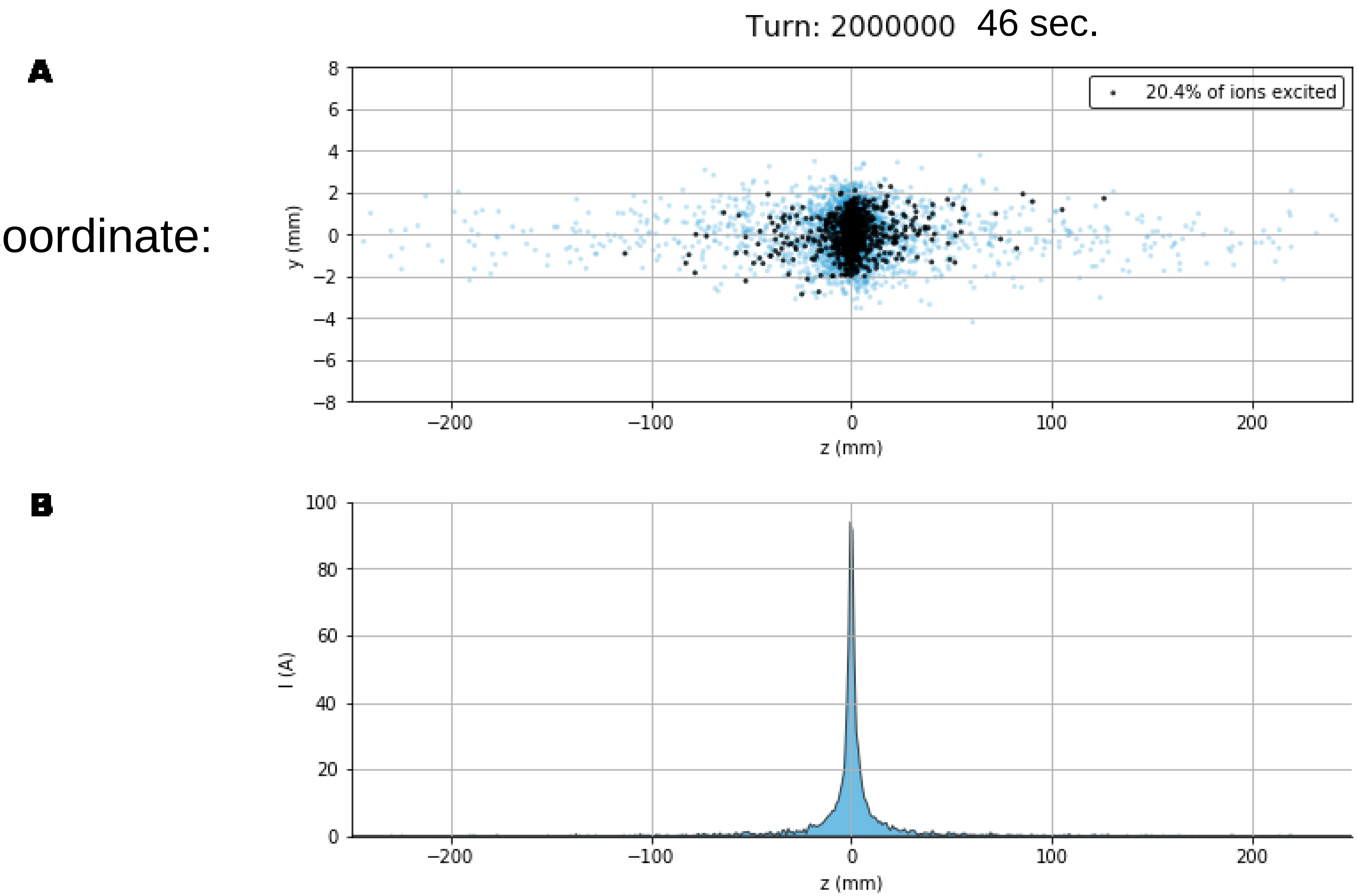
Vertical coordinate:



SPS PoP Experiment Cooling
2.6 degrees crossing angle, 5 mJ laser, σ(Δp/p)=2e-4:

Vertical coordinate:



Conclusions

It looks like with the new ion beam parameters ($\sigma(\Delta p/p)$=2e-4 instead of 3e-4) the cooling becomes faster!

Just in general this confirms that we can cool the central part of the bunch much faster than the outer part.

The energy stability of the SPS beam should be included into the simulation.
+ intrabeam scattering and high-frequency impedances.