LhARA: Progress on Laser Source Simulations

Hin Tung Lau

May 11, 2021

Beam Tracking Simulations as in Pre-CDR

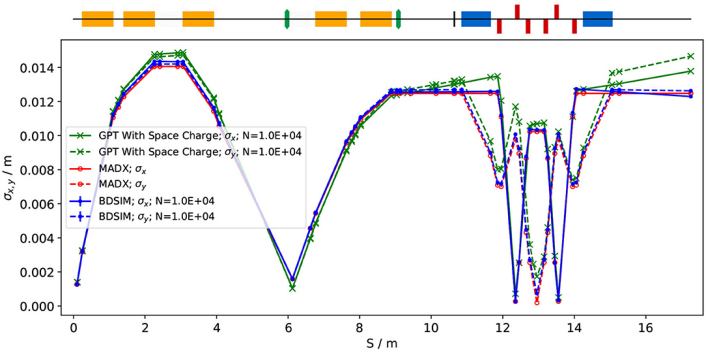


Figure: Beam line tracking with ideal beam.

- Previously tracked an ideal beam through the beamline.
- There was also a “physical” beam based on old 2D EPOCH simulation.
- But was limited in usefulness due to:
  - Old laser parameters
  - Limited number of particles
  - No positional space information.
- Aim is to update laser-plasma interaction simulations and tracking.

Simulation Codes for Stage 1 Tracking

Smilei

- Particle-In-Cell (PIC) code for plasma simulation.
- Generate distribution of particles.

BDSIM

Beam Delivery Simulation

- Uses Geant4 toolkit to simulate transport and particle-matter interactions.
- Propagates beam from Smilei through beam line.

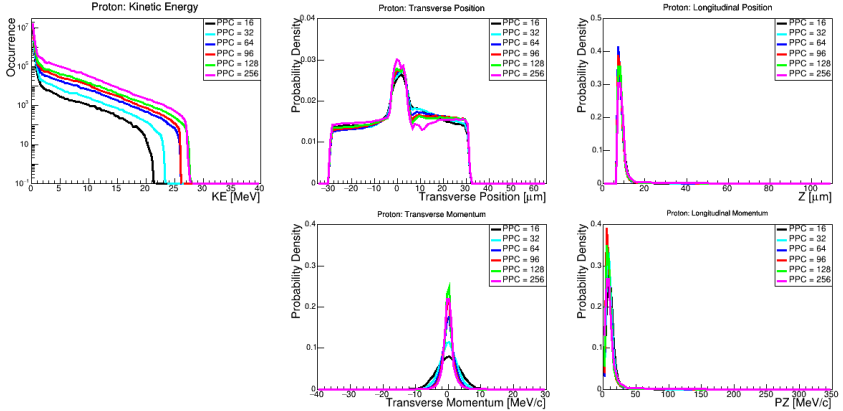
GPT

General Particle Tracer

- 3D particle tracking with various 2D and 3D space charge models.
- Include space charge effects in distribution.

Smilei Simulations

- First step was to avoid numerical effects affecting the simulation results, this involved convergence testing.



- Settled on using a ppc = 128 and a resolution of 5 nm in the longitudinal and 10 nm in the transverse.

Dimensionality Problem

- Ideally we would run a 3D simulation and track the protons through the beamline...
  - Was not feasible to simulate on HPC cluster due to: Time, Resources, and Memory.
- However, a 2D simulated macroparticle **energy spectrum is enhanced** compared to 3D simulations to experiments.
- Without the laser system to compare against, had to accept that we can only generate and track a **qualitative** beam.
- We decided to sample the 2D simulation assuming that the **same correlations** would be present for the **artificially** added transverse dimension.
  - Beam not entirely directly sampled, the kinetic energy was sampled directly but to conserve momentum, the momentum is recalculated.

Smilei 2D Simulation for Proton Macroparticles

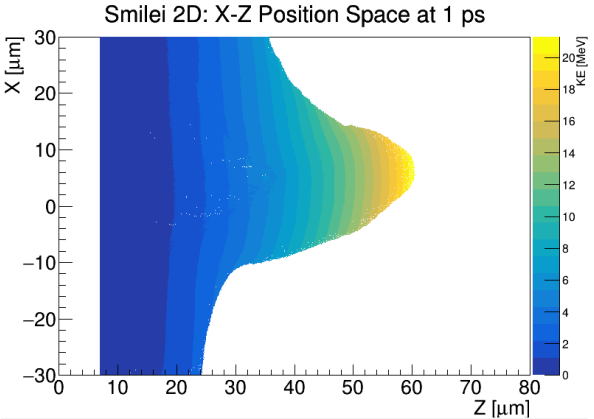


Figure: 2D positional spread of proton macroparticles.

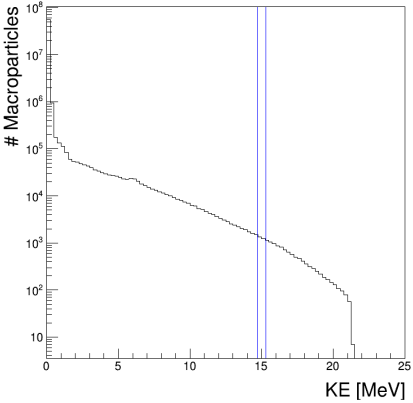
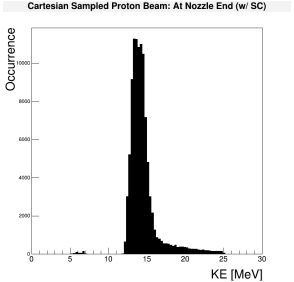


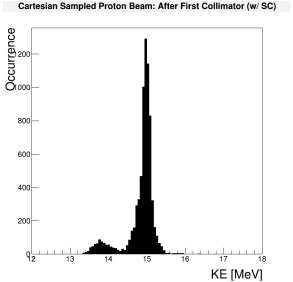
Figure: Kinetic energy spectrum for proton macroparticles. Blue bars signify energies around 15 MeV.

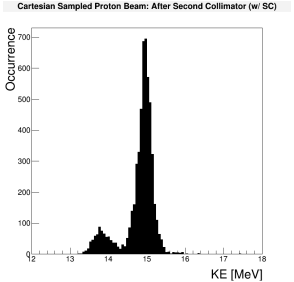
- From simulation, proton macroparticles from beam are off-centred and only a small proportion are energies we are interested in.

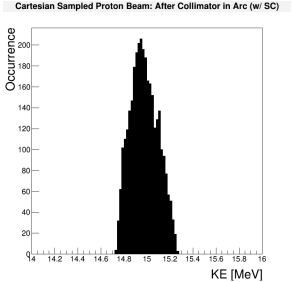
Collimators and Energy Distribution

- For energy selection, collimators were included in the beamline
- Results of collimation for KE $\geq$ 5 MeV

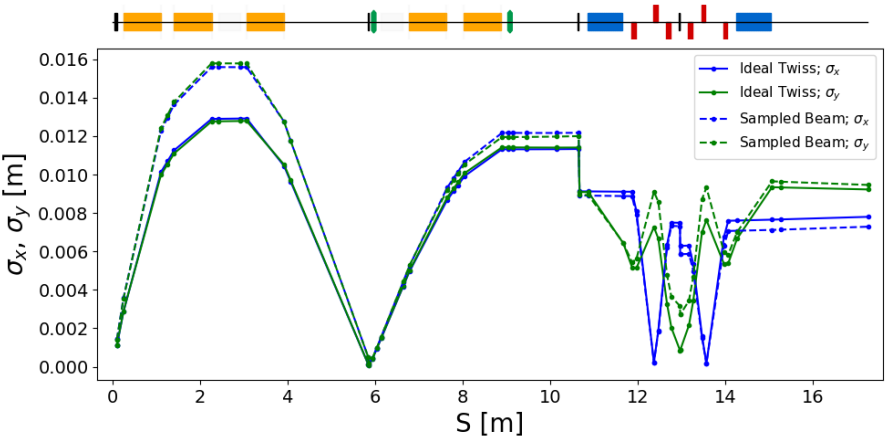








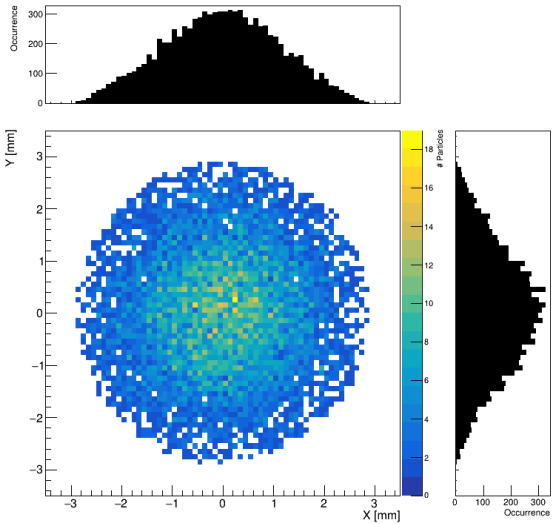
Beam Size Evolution Comparison



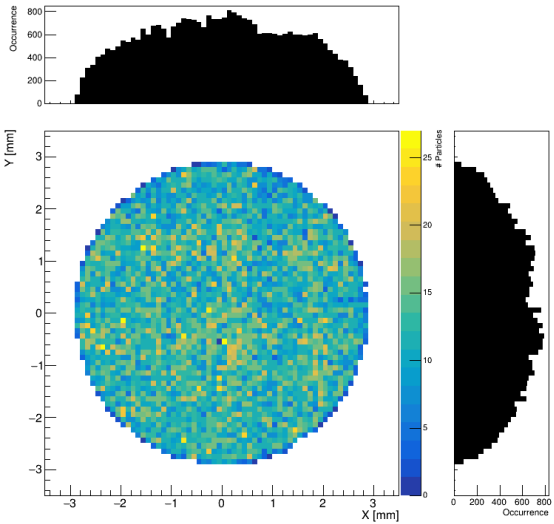
- Ideal beam simulation repeated but included nozzle and other collimators.
- Space charge effects included for both beams.
- For energies $14.7 < \text{KE} < 15.3\,\text{MeV}$

Transverse Position Space Comparison after Nozzle

Ideal Beam: End of Nozzle

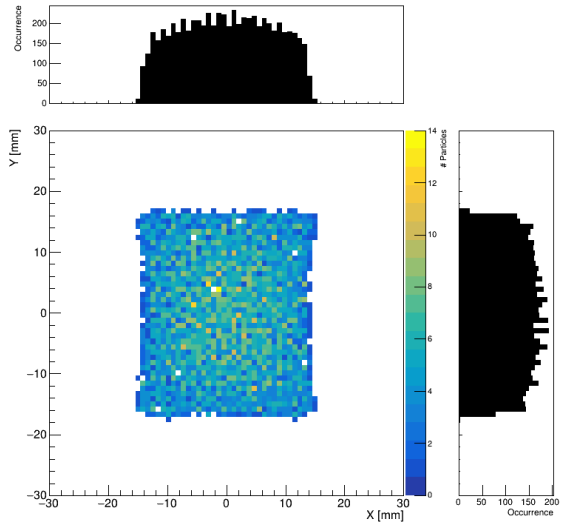


Sampled Beam: End of Nozzle

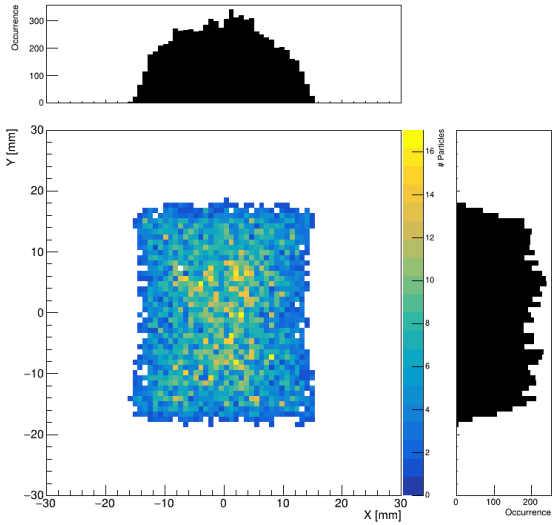


Transverse Position Space Comparison at End Station

Ideal Beam: Stage 1 End

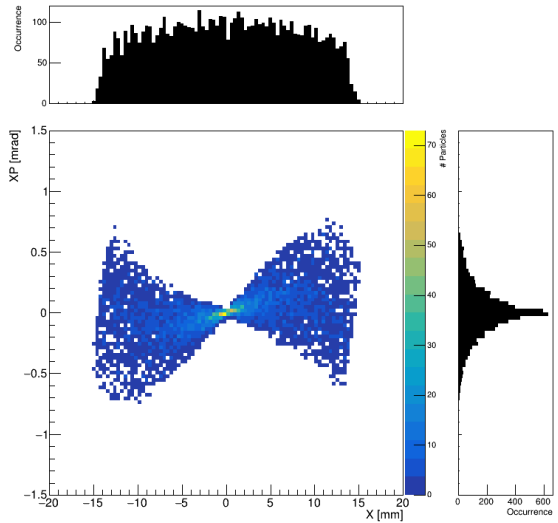


Sampled Beam: Stage 1 End

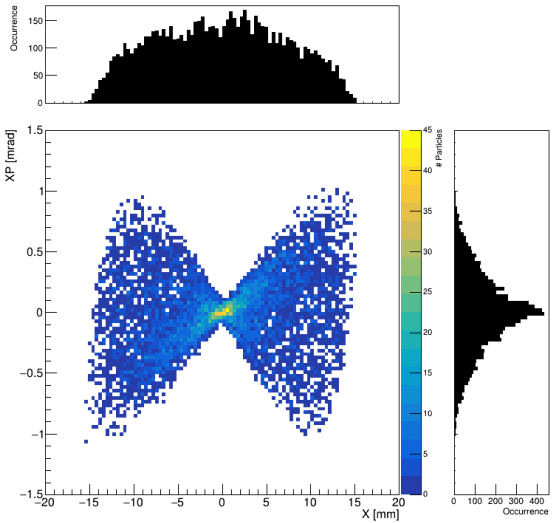


Transverse Phase Space Comparison at End Station

Ideal Beam: Stage 1 End



Sampled Beam: Stage 1 End



Conclusion

- Tracked a **qualitative** beam from laser source through Stage 1 beamline.
- Comparing tracking to ideal beam at 15 MeV shows that although beam initially looks different, comparable at the end.
  - Shape of spatial distribution a bit different.
  - Sampled beam also seems to have a larger divergence.
- Some odd characteristics still being understood.