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Simulations of an Electron Lens

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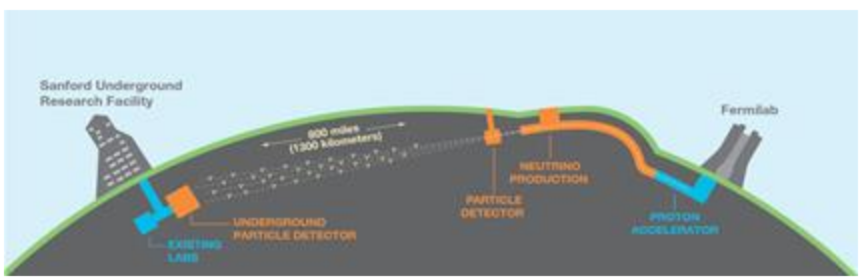
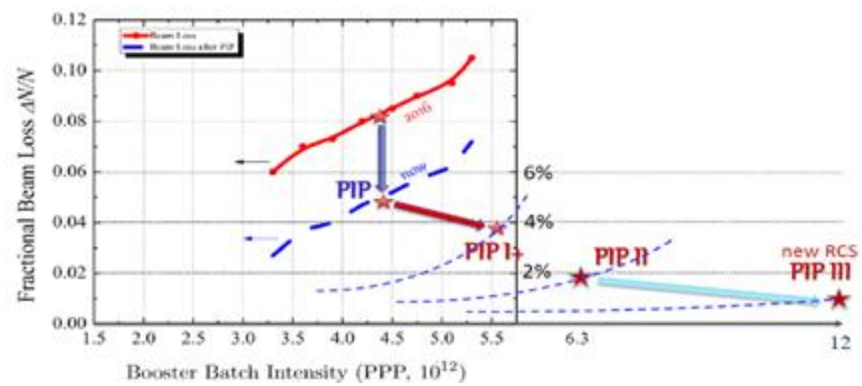
Motivation

- DUNE (Deep Underground Neutrino Experiment)
  - NOvA 500 Miles -> DUNE 800 Miles
  - Detector events scale with $\frac{1}{r^2}$
  - Already few events per day
  - Scale beam intensity by 4x
  - Losses at regulatory maximum
- 900 kt·MW·years of exposure
  - 50 Years with current technology
  - Space charge contributes to increased losses

Source: [5]



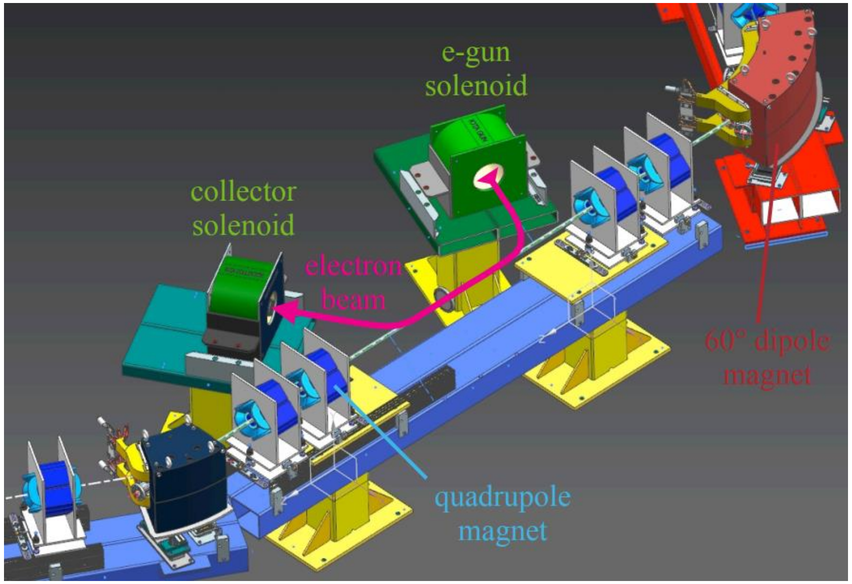
Source: Duneforce.org



Credit: [1]

Electron Lens

- Nonlinear element of lattice
- Low-beta Electron beam
- Can control bunch size and intensity
- Compensate space charge
- Radially symmetric kick



Source: [3]

- In IOTA:
  – Recycled from Tevatron beam-beam compensation
  – Space charge compensation

IOTA (Integrable Optics Test Accelerator)

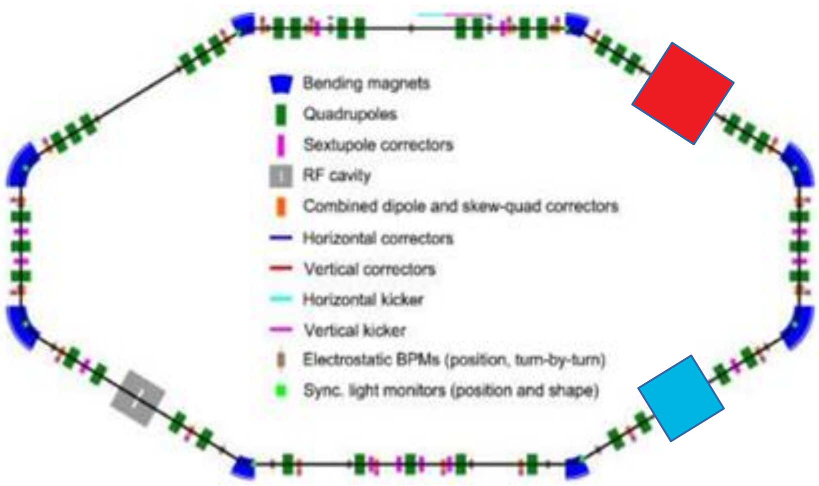
- Experimental Storage Ring:
  - Low-beta Electrons and Protons
  - 40m circumference
  - Non-Linear Magnets, Electron Lens, Electron Columns

- IOTA Timeline:
  - Nonlinear Integrable Optics
    - Phase 1: Electrons 2018-2020
    - Phase 2: Protons 2020-2022
  - Space-charge compensation with electron lens
    - **Electron Lens 2020-2022**
    - Electron Column 2022-2023

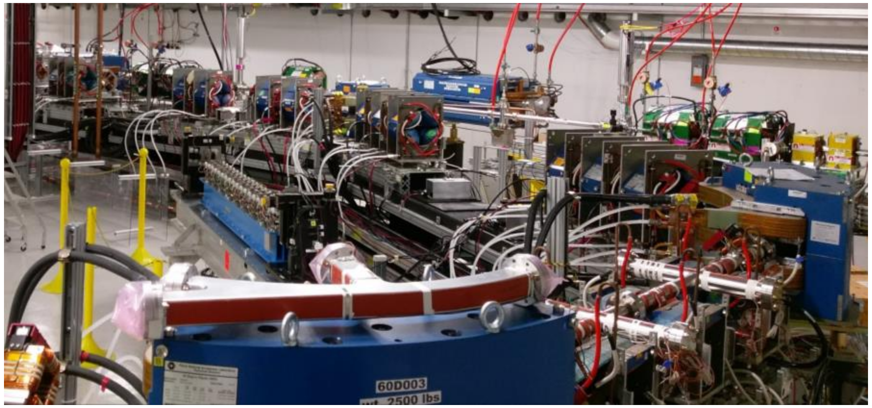
Source: [4]

- Electron lens predicted to compensate space charge by a factor of 2

The IOTA Lattice

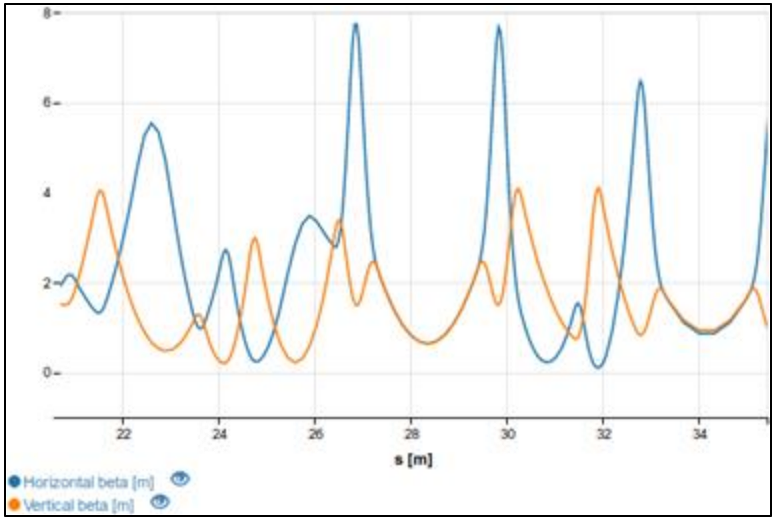


Source: [1]



Source: [2]

Red: Where electron lens is in our simulations
Blue: Where actual electron lens will be located



Horizontal and Vertical β-functions

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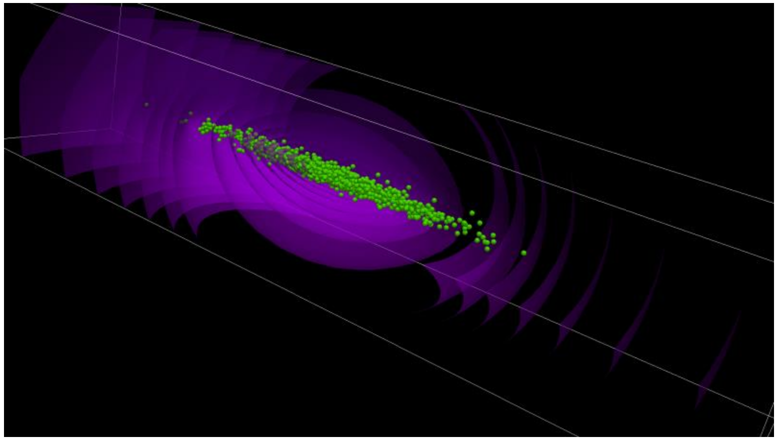
Synergia

- 6D Accelerator Simulation
- Can take MADX lattices
- C++ Functions wrapped in Python
- Perfect option for our simulations:
  - Accommodates collective effects (e.g. Space charge)
  - Has functionality to create elements
- Electron Lens simulated before?



Green spheres: Particles

Purple waves: Contours of constant electric potential

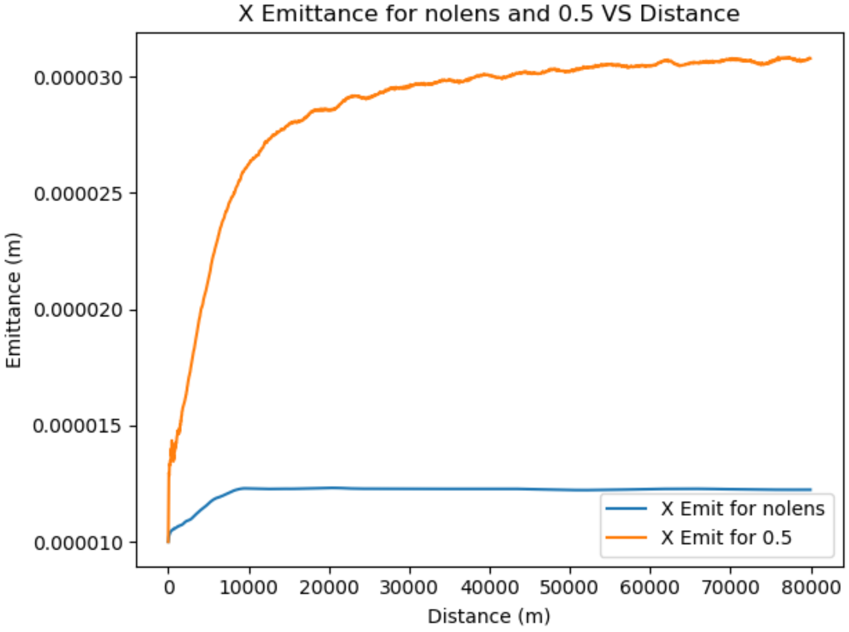
Source: web.fnal.gov/sites/Synergia

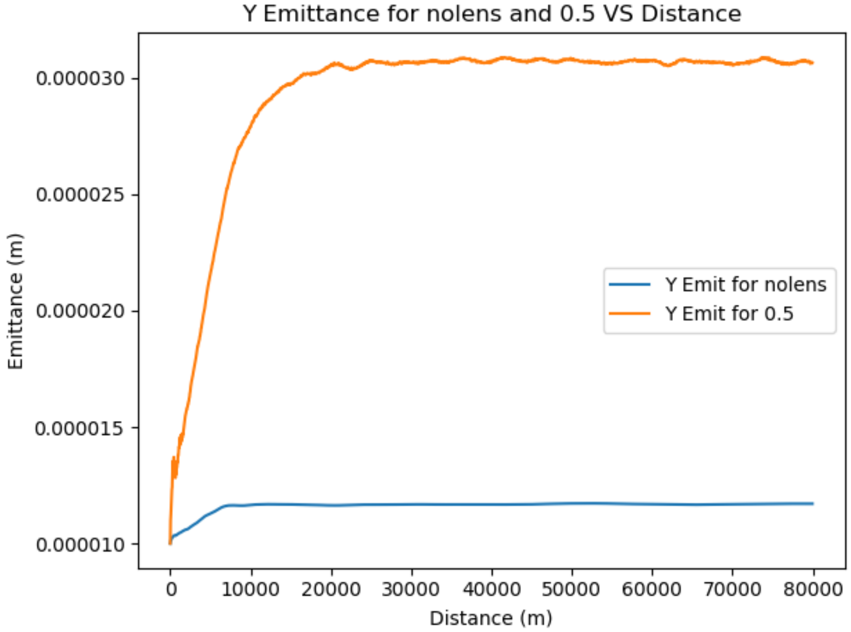
Simulation parameters

- Took parameters from IOTA documentation
- Altered until tune shift was 0.2

Parameter	Value
Proton Kinetic Energy	2.5 MeV
Real Particles	2.25E9
Macroparticles	1E5
Emittance	1E-5
Bunch Length	1.7 m
Turns	2000
Electron lens current	0.5 A
Electron lens RMS	Sqrt(Emittance * β)
Electron lens distribution	Gaussian

Results – Emittance





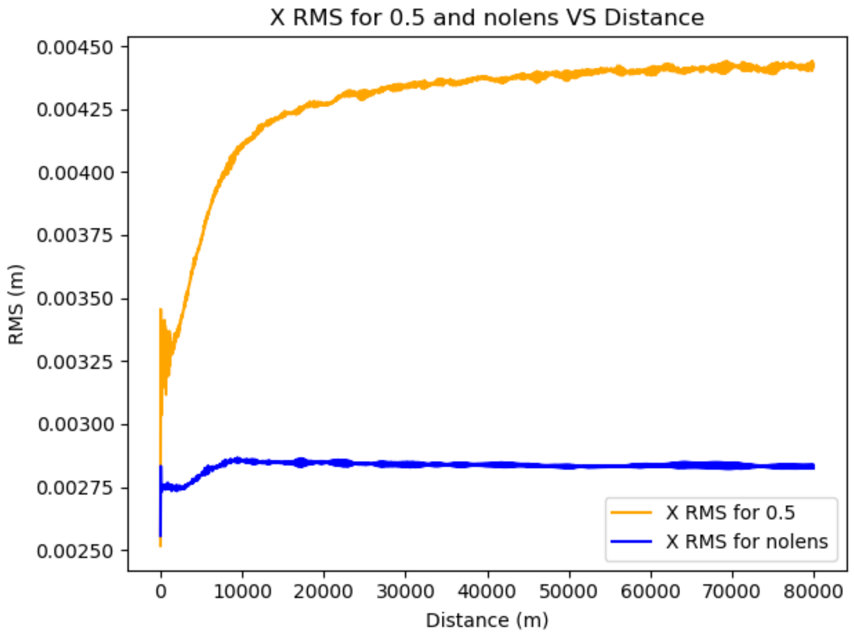
X Emittance

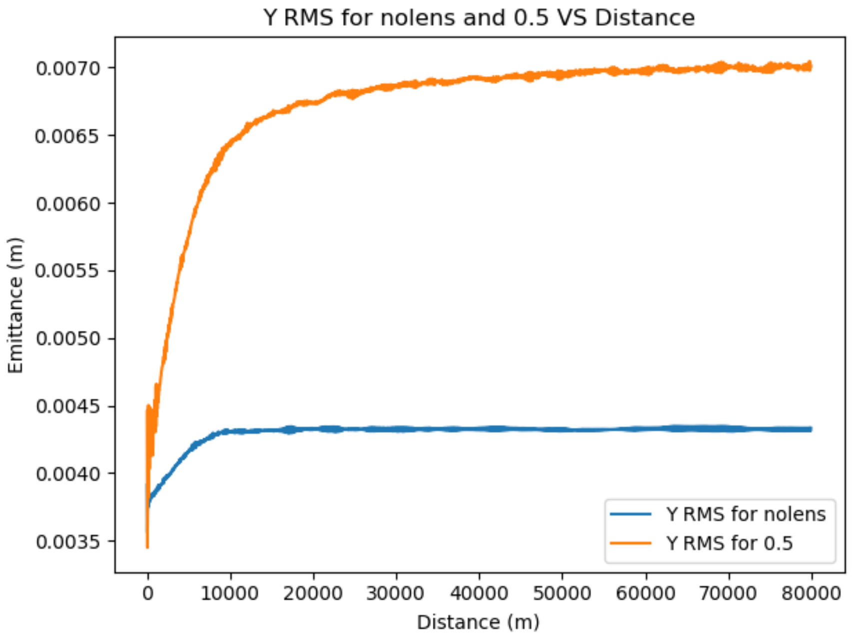
Y Emittance

Orange: Electron lens at 0.5 A

Blue: No electron lens

Results – RMS





X RMS

Y RMS

Orange: Electron lens at 0.5 A

Blue: No electron lens

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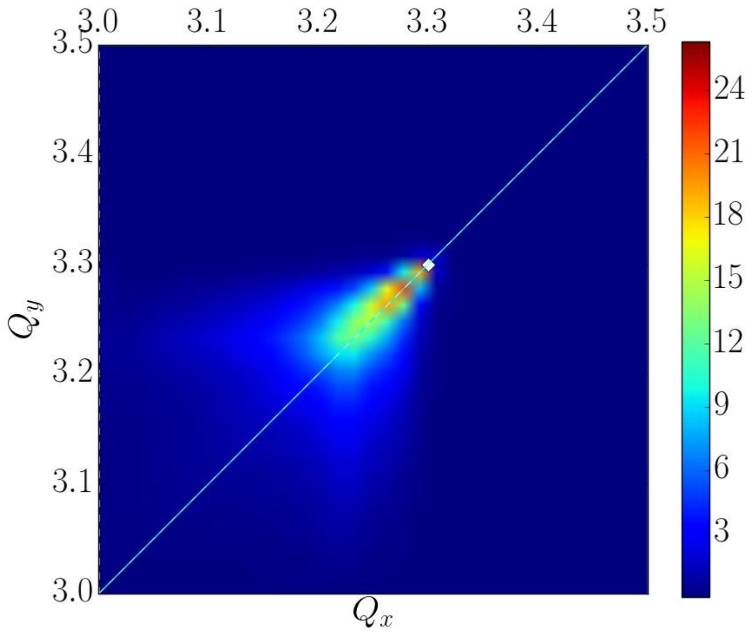
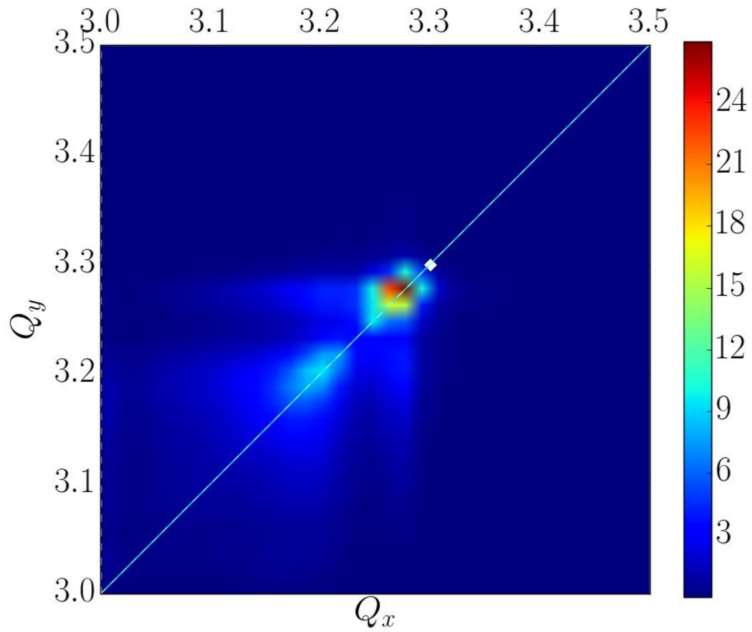
Results – Tune Footprint





- No Electron Lens
- White dot: Tune with no space charge
- Spread due to space charge

- With Electron lens of 0.5 A
- Calculated Tuneshift: 0.166

Conclusion

- Benefits in beam stability were not realized in simplified IOTA simulations

Simulation code: https://github.com/TFranczak/Synergia

Computing Resources: https://jupyter.radiasoft.org

Questions?

Acknowledgements

- Eric Stern and Jim Amundson
  - Mentors who greatly aided the research process
- Radiasoft
  - Sirepo and computing resources

Bibliography

[1] Sergei Antipov, Vladimir Shiltsev, et al. Iota (integrable optics test accelerator): Facility and experimental beam physics program. 2016.

[2] Valishev, Alexander (2018). Status of Integrable Optics Test Accelerator [PowerPoint slides]. Retrieved from https://indico.fnal.gov/event/16269/contribution/30/material/slides/0.pptx.

[3] Stancari, Giulio (2018). IOTA electron lens: nonlinear optics, cooling, and space-charge compensation [PowerPoint slides]. Retrieved from https://indico.fnal.gov/event/16269/contribution/41/material/slides/0.pdf.

[4] V. Shiltsev, "2018 Accelerator and Beam Physics GARD Review", July 31, 2018, Fermilab, Retrieved from https://indico.fnal.gov/event/17718/

[5] Shiltsev, Vladimir (2017). Fermilab proton accelerator complex status and improvement plans. Modern Physics Letters A, 32(16), 1730012. https://doi.org/10.1142/s0217732317300129