HL-LHC-BGI:
Investigating Beam Offset & Time of Flight

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HL-LHC BGI Analysis – 25th March, 2024

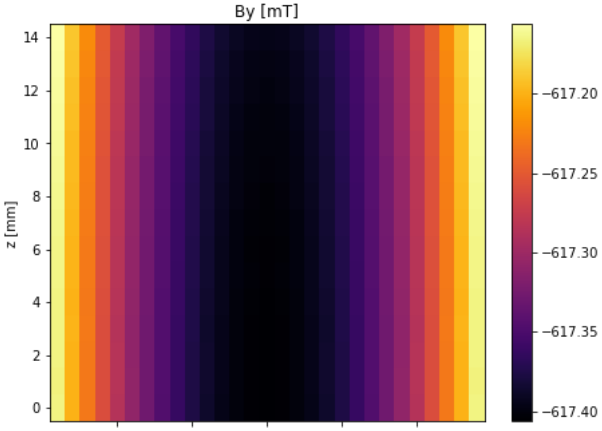
New Designs Under Consideration

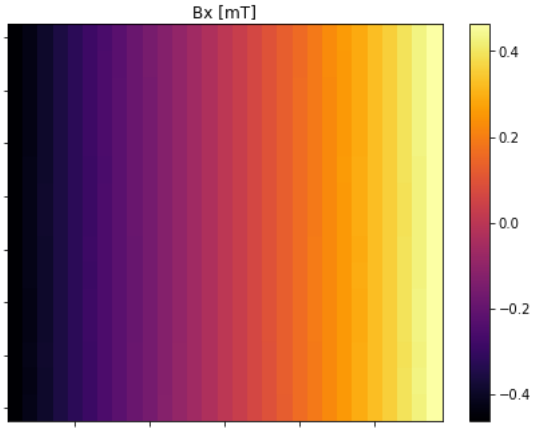
Rolls-Royce Doublet Magnet

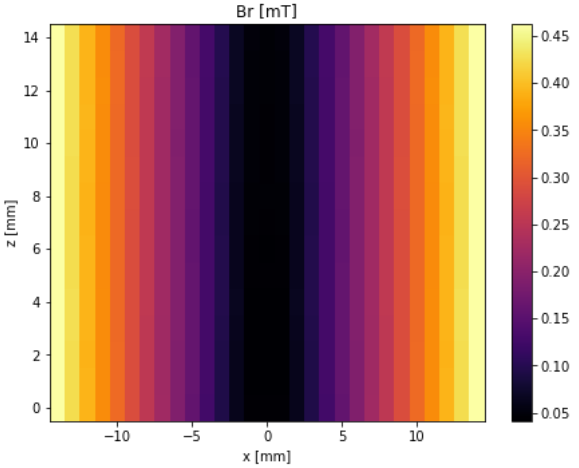
- $B_y = 617.32 \pm 0.08\ \mathrm{mT}$

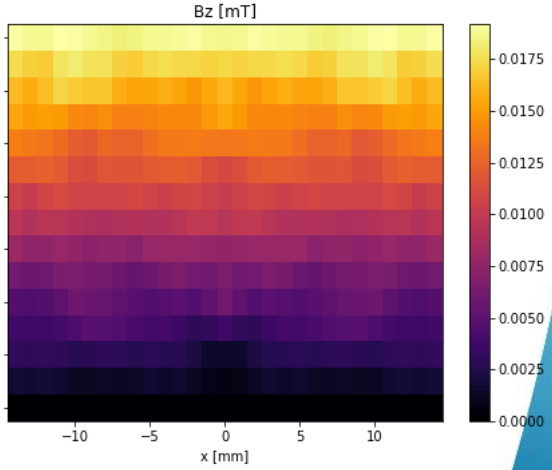
  $(0.01\%\ \mathrm{error})$

- $B_r = 0.2 \pm 0.1\ \mathrm{mT}\left(\frac{B_r}{B_y} \times 100\% = 0.04\%\right)$





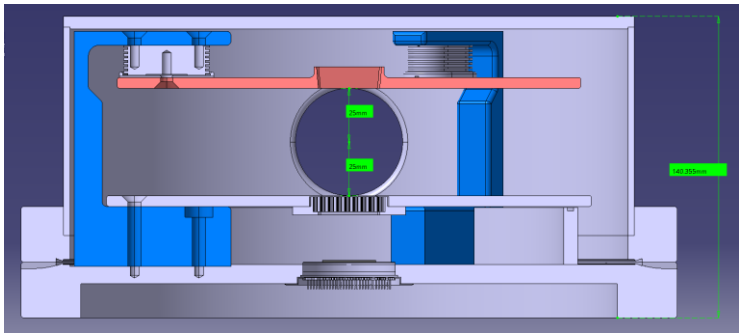


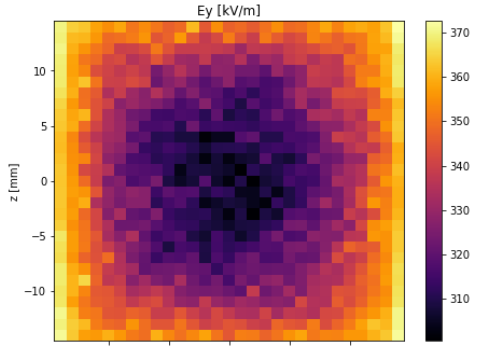


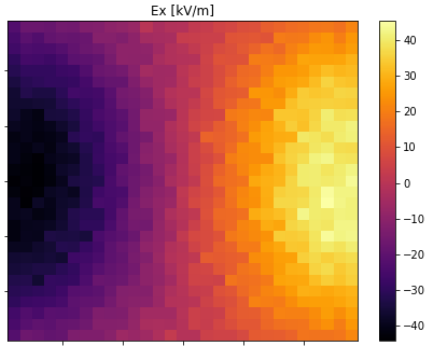
Latest Iteration of the CF250 Design

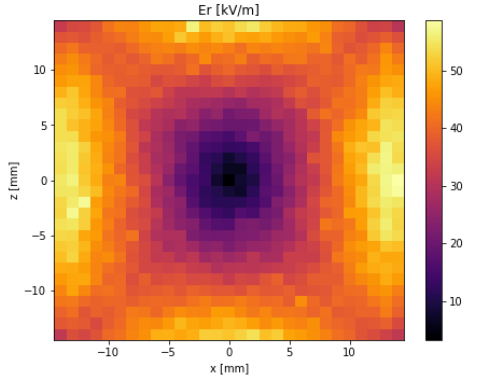
- $E_y = 340 \pm 20 \frac{\text{kV}}{\text{m}}$
  (5.3% error)

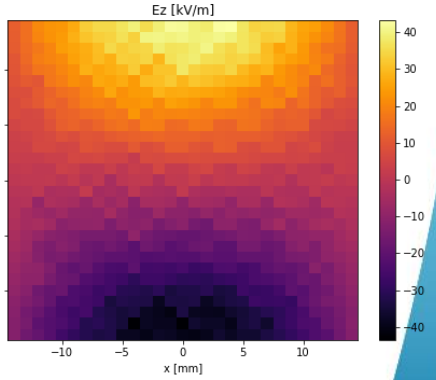
- $E_r = 40 \pm 10 \frac{\text{kV}}{\text{m}}$
  $\left(\frac{E_r}{E_y} \times 100\% = 11\%\right)$









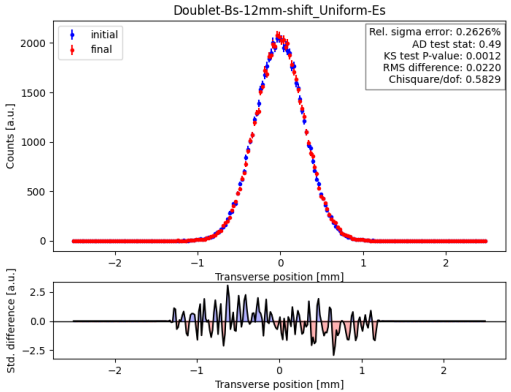


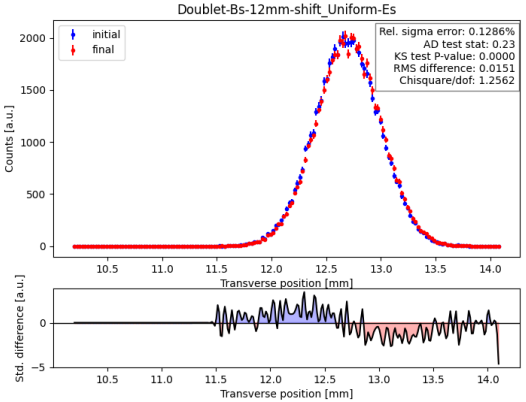
Consider $\Delta y_{e^-} \sim 25$ mm

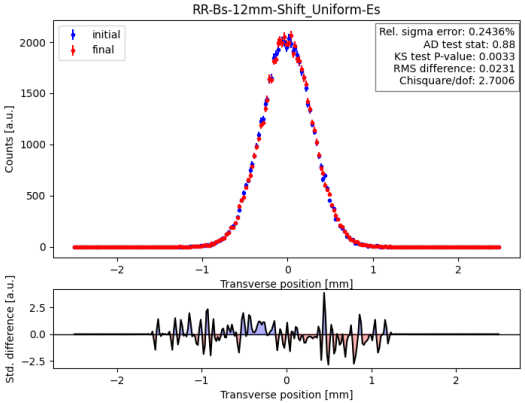
Uniform Electric Field with 12mm Es-Bs Offset

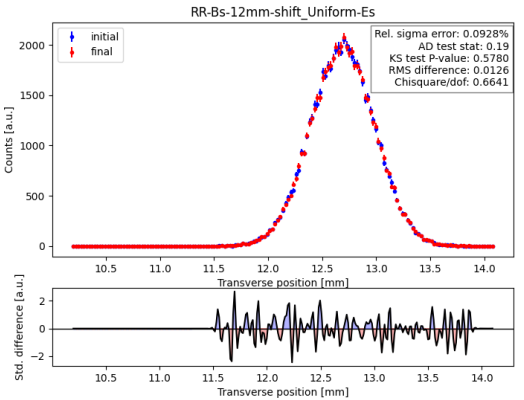
Doublet Magnet

Triplet Magnet



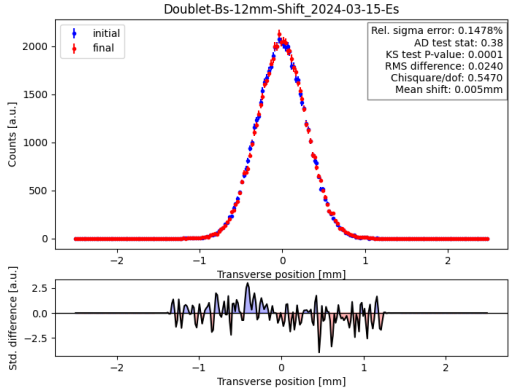


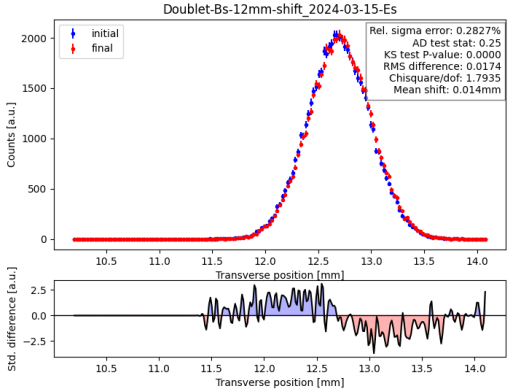




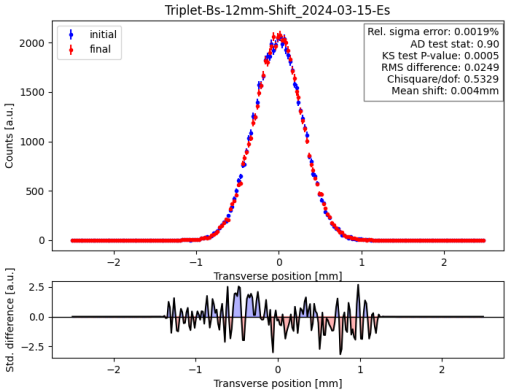
Latest CF250 Design with 12mm Es-Bs Offset

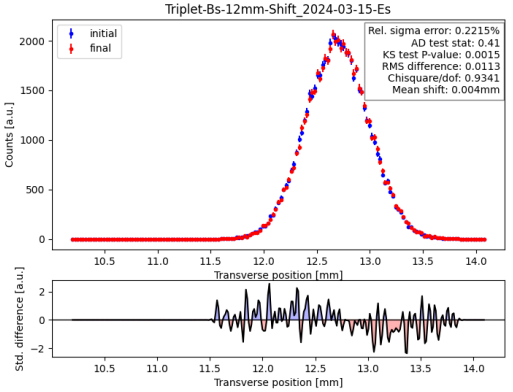
Doublet Magnet





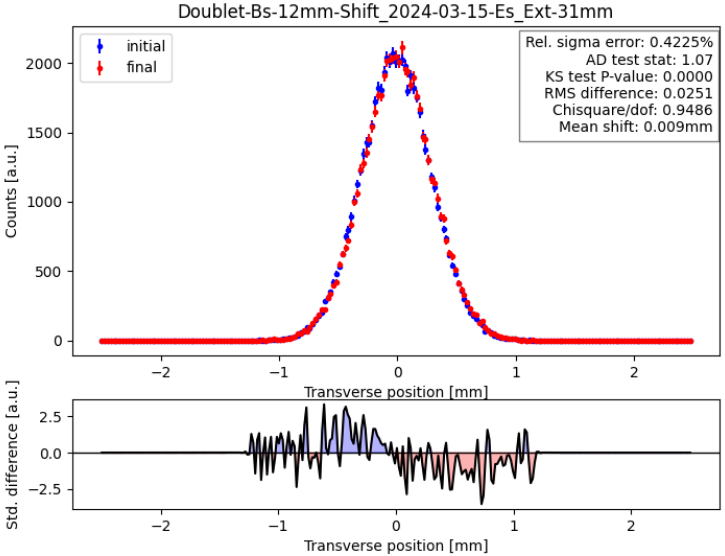
Triplet Magnet

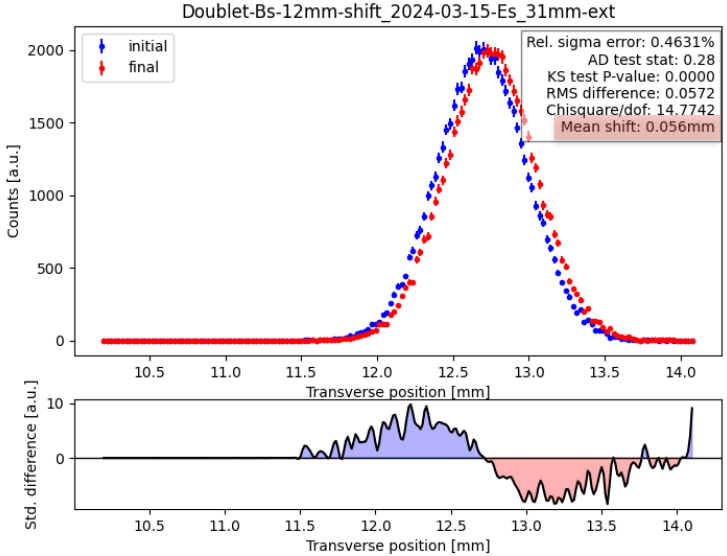




Consider $\Delta y_{e^-} \sim 56$ mm

Doublet Magnet with Latest CF250 Design



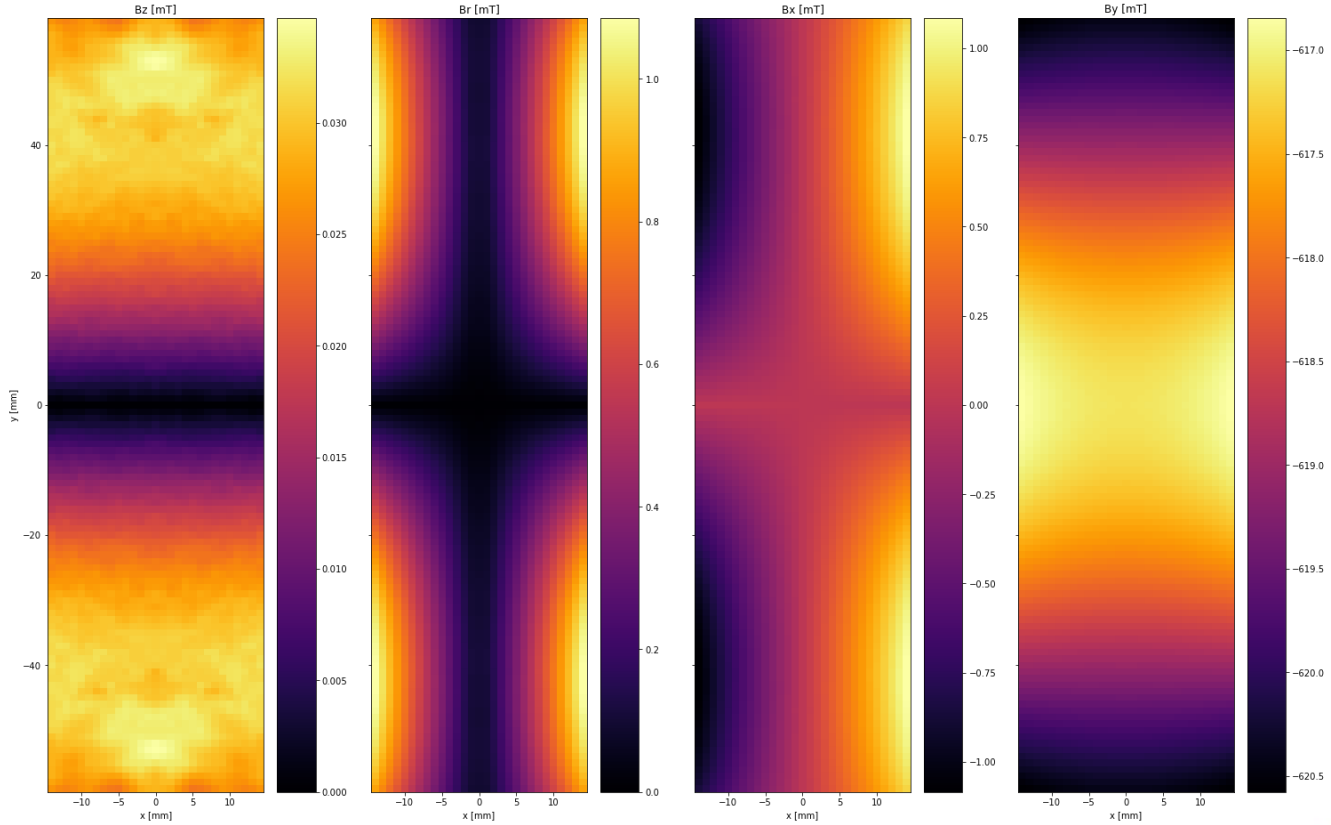


Conclusion

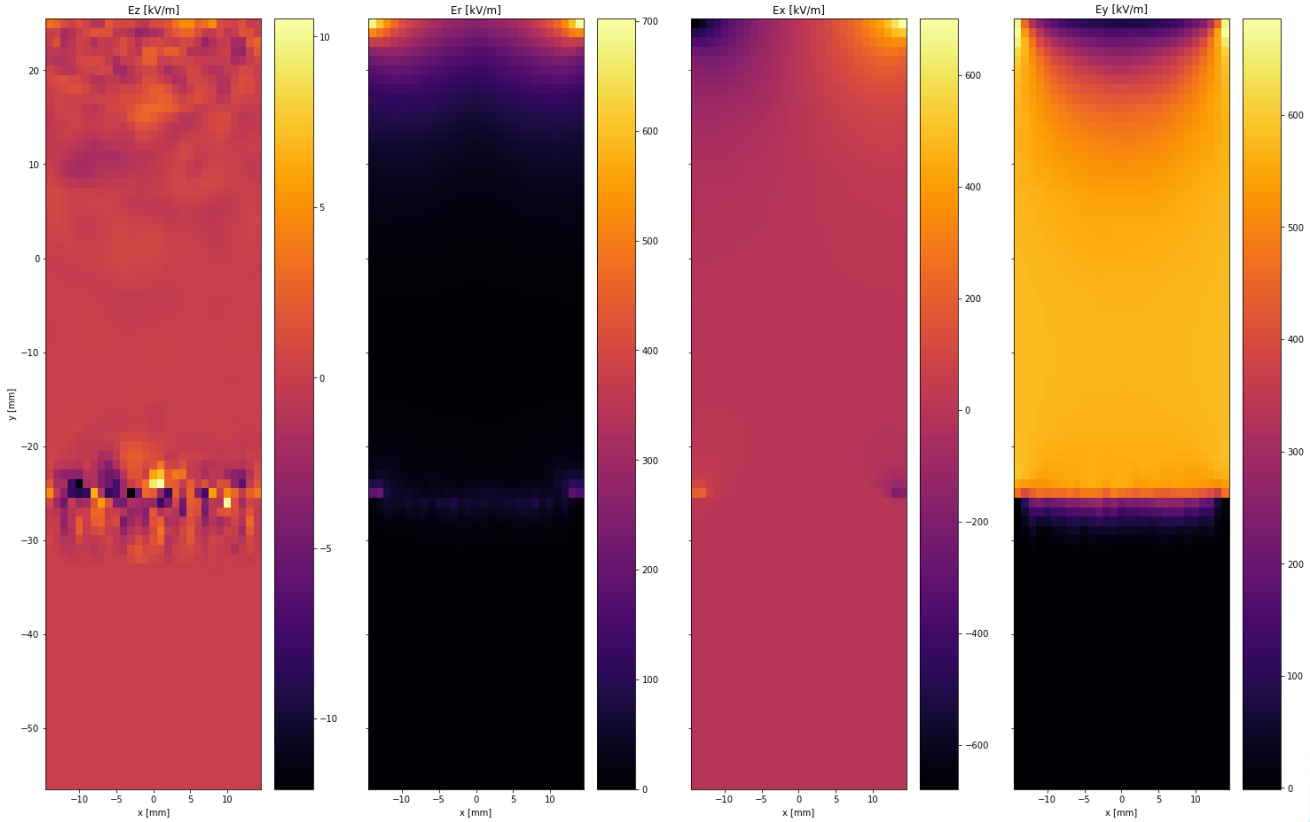
- Triplet magnet performs slightly better than doublet magnet, but **all simulations demonstrate <1% relative sigma error**
- Shifting effects seen for the doublet magnet when beam is are 12.7mm in the x-direction. These **effects are compounded with additional 31 mm gap between the anode and the Timepix3**, such that shift is >55um.

Appendix

Rolls-Royce Doublet Magnet

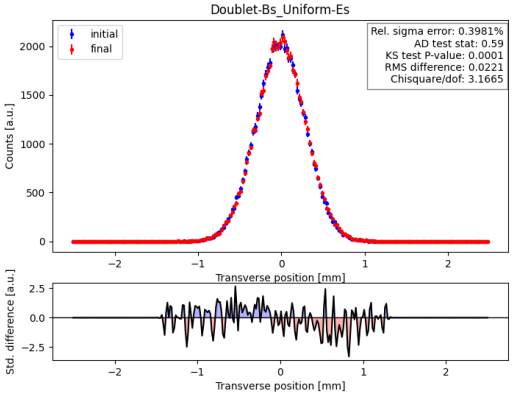


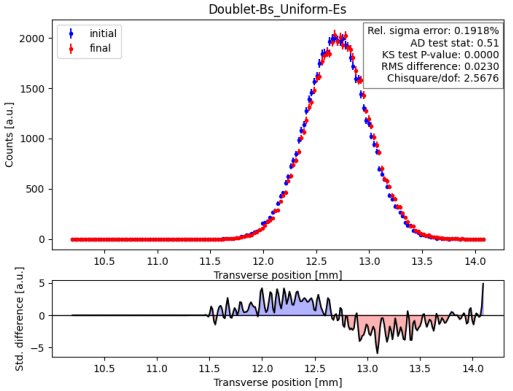
Latest Iteration of the CF250 Design



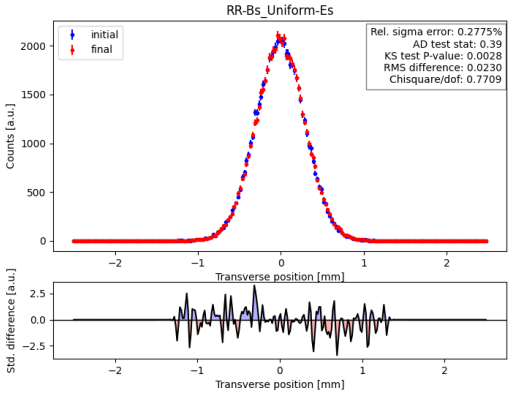
Uniform Electric Field

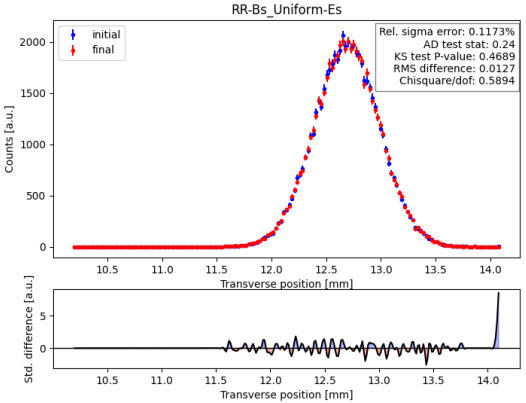
Doublet Magnet



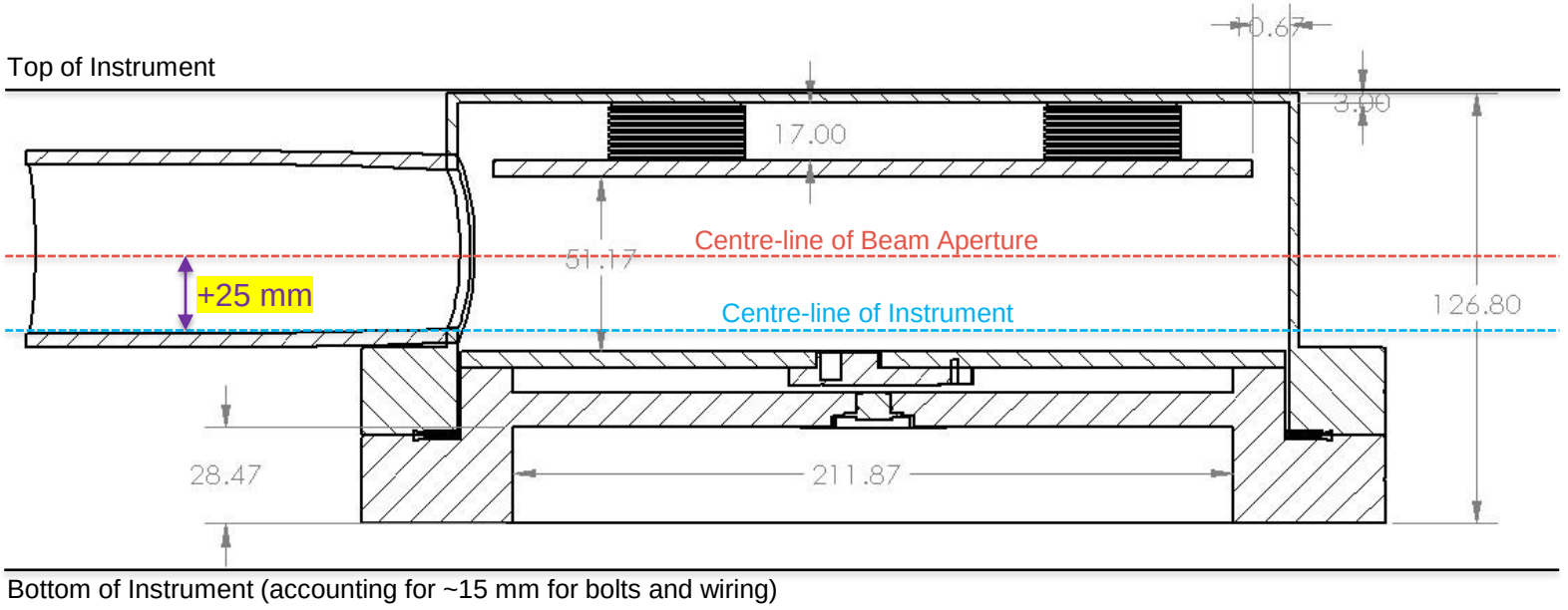


Triplet Magnet





Aperture-Instrument Offset for Conceptual Design



Time of Flight

Time of Flight Overview

- Require **< 25 ns spread of time of arrivals (ToAs) per bunch** to allow bunch-by-bunch measurements
- Approximate ToA:

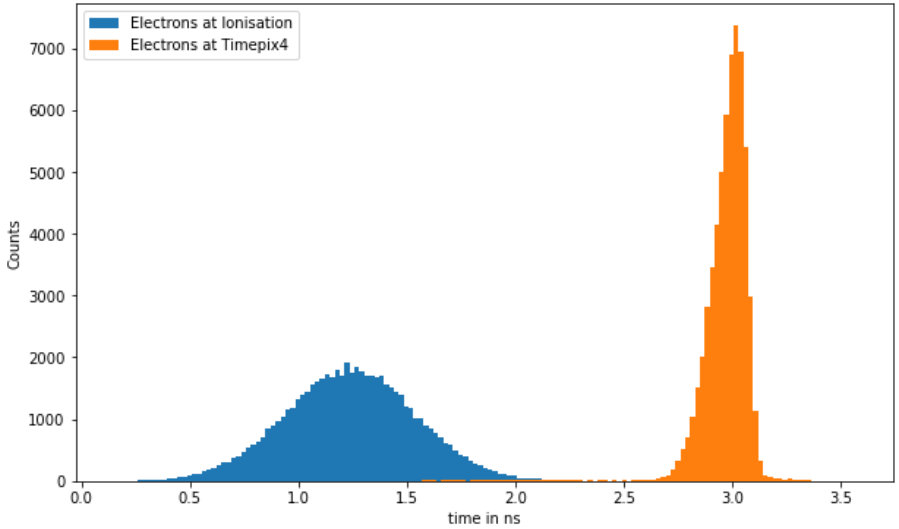
Assume negligible space charge and uniform electric and magnetic fields

$$y_i = \frac{-qE}{2m}\Delta t^2 - v_y \Delta t \implies \Delta t \sim 1\, ns$$

- Simulations account for non-uniform electric fields, magnetic fields and space charge effects. They tell us the **spread** of ToAs.

Time of Flight Evaluation for “Worst Case”

- Simulated with 56mm path length
- Using Doublet magnetic field and latest iteration of the BGI’s electric field (30 kV cathode)
- Accounts for off-center beam aperture within magnetic field



Conclusion: Spread of electron arrival times is sufficiently small for bunch-by-bunch measurements

Consider Vertically Off-Centre Beams

Varying y-position of Beam

- Simulations done beam centered in x, no offset between electric and magnet fields, and triplet magnet
- BSRT estimates beam drifts no more than 1 mm
- Thus, beam should be **< 26 mm away from the anode**