Transfigured Electron Double Slit Experiment

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Overview

- Motivation
  - Unsettled issues of Quantum Mechanics
  - Unexplained experiments
- Overview of TEDSE
- Implications of a positive result
- Ongoing Effort with Calculations and Simulations
- Proposal submitted to Program Office and Joe Lykken October, 2016

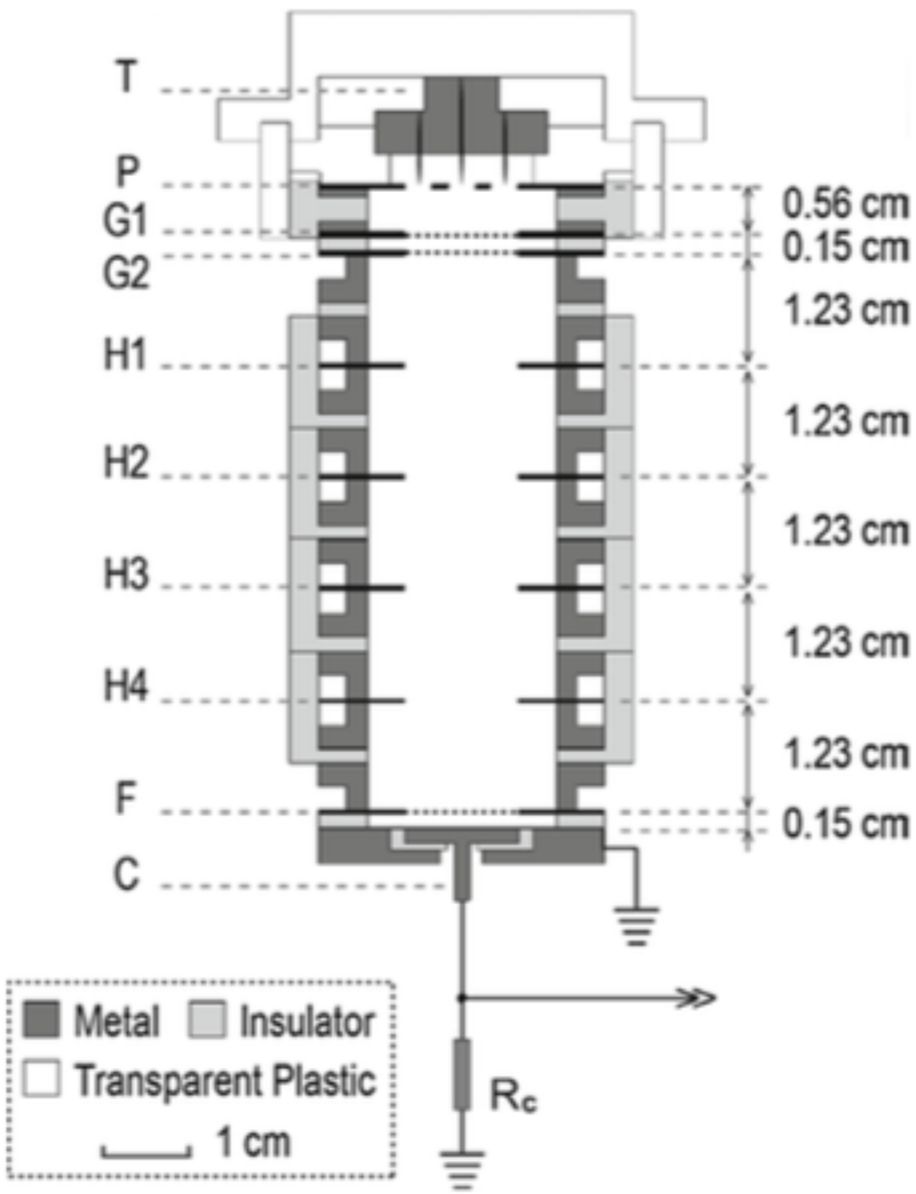
History and Motivation

- Effect: Electron wave functions split between superfluid helium bubbles in four laboratories beginning in 1969 to present (Helium bubble is a quantum object consisting of a relatively large number of superfluid helium atoms surrounding an electrons. Electrons do not penetrate the helium without forming a bubble)

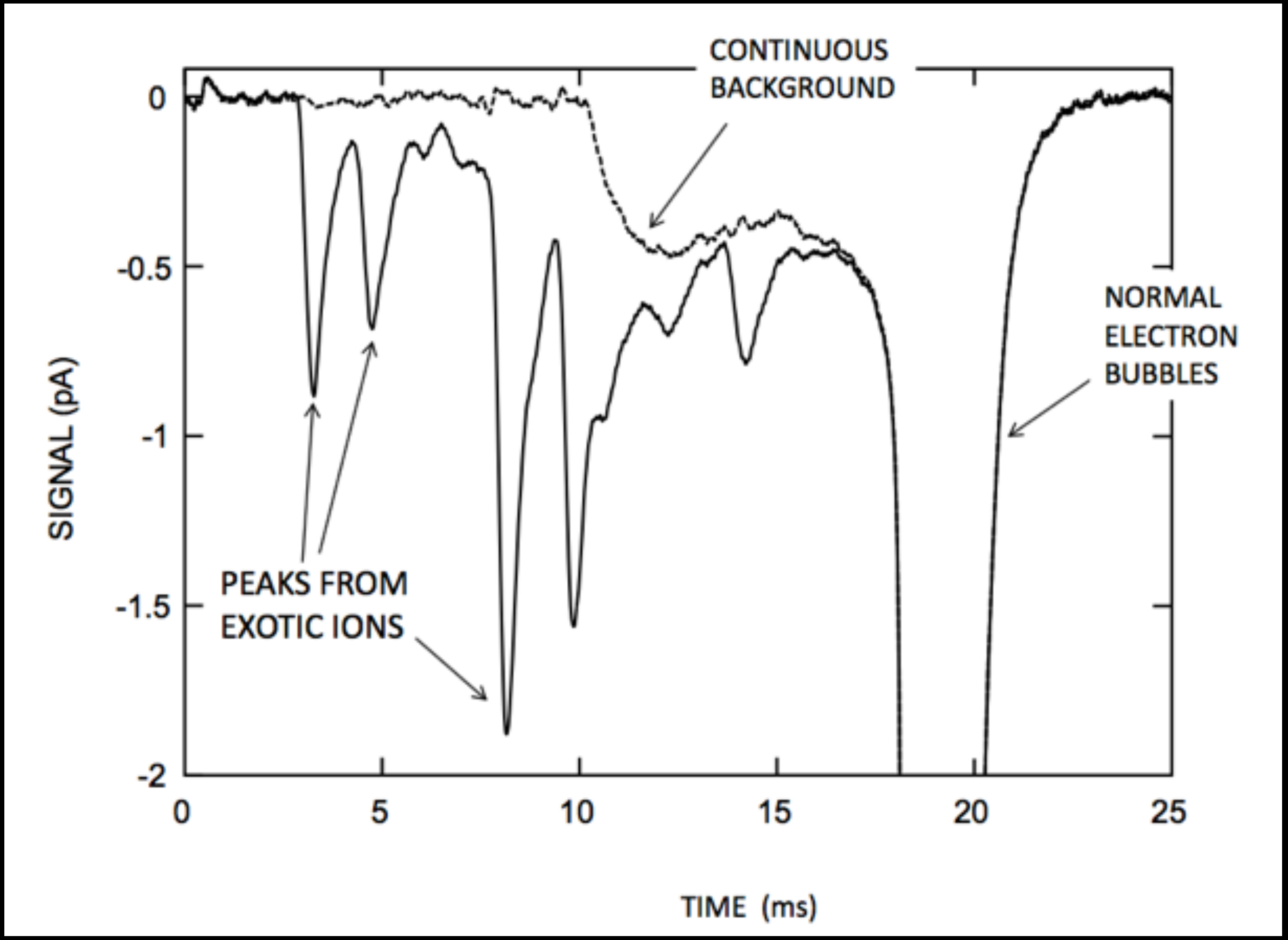
- Each saw the effect with increasing resolution
  - St. Andrews (Scotland)
  - University of Michigan
  - Lancaster University
  - Brown University

Experiments

Fig. 2 Cross-section through the experimental cell showing the tungsten tips T, the perforated plate P, gate grids G1 and G2, field homogenizer disks H1–H4, Frisch grid F and ion collector C



Results



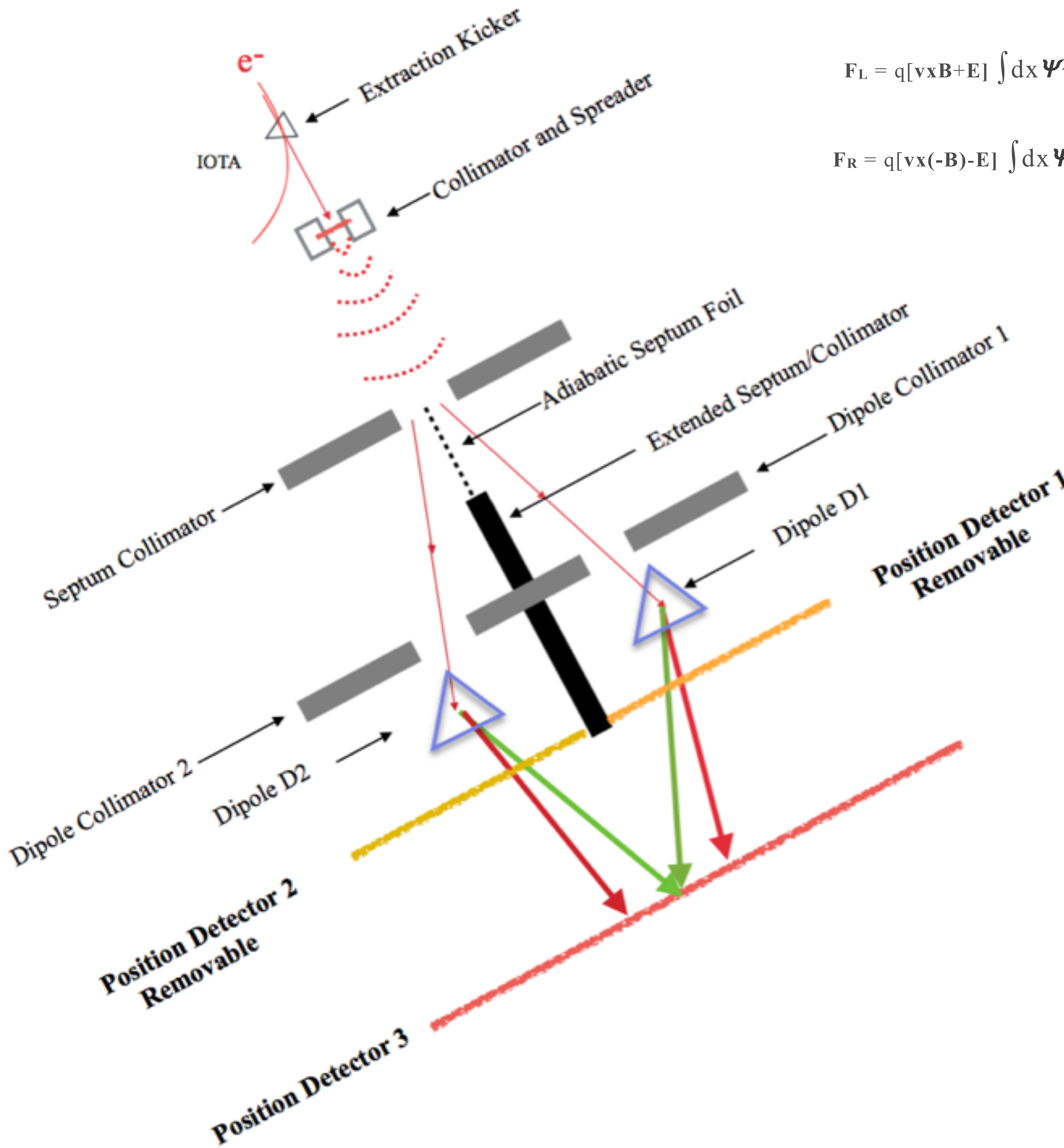
What could arrive faster than an electron?
Wave function spread over more than one bubble and trapped in each? What constitutes a quantum measurement?

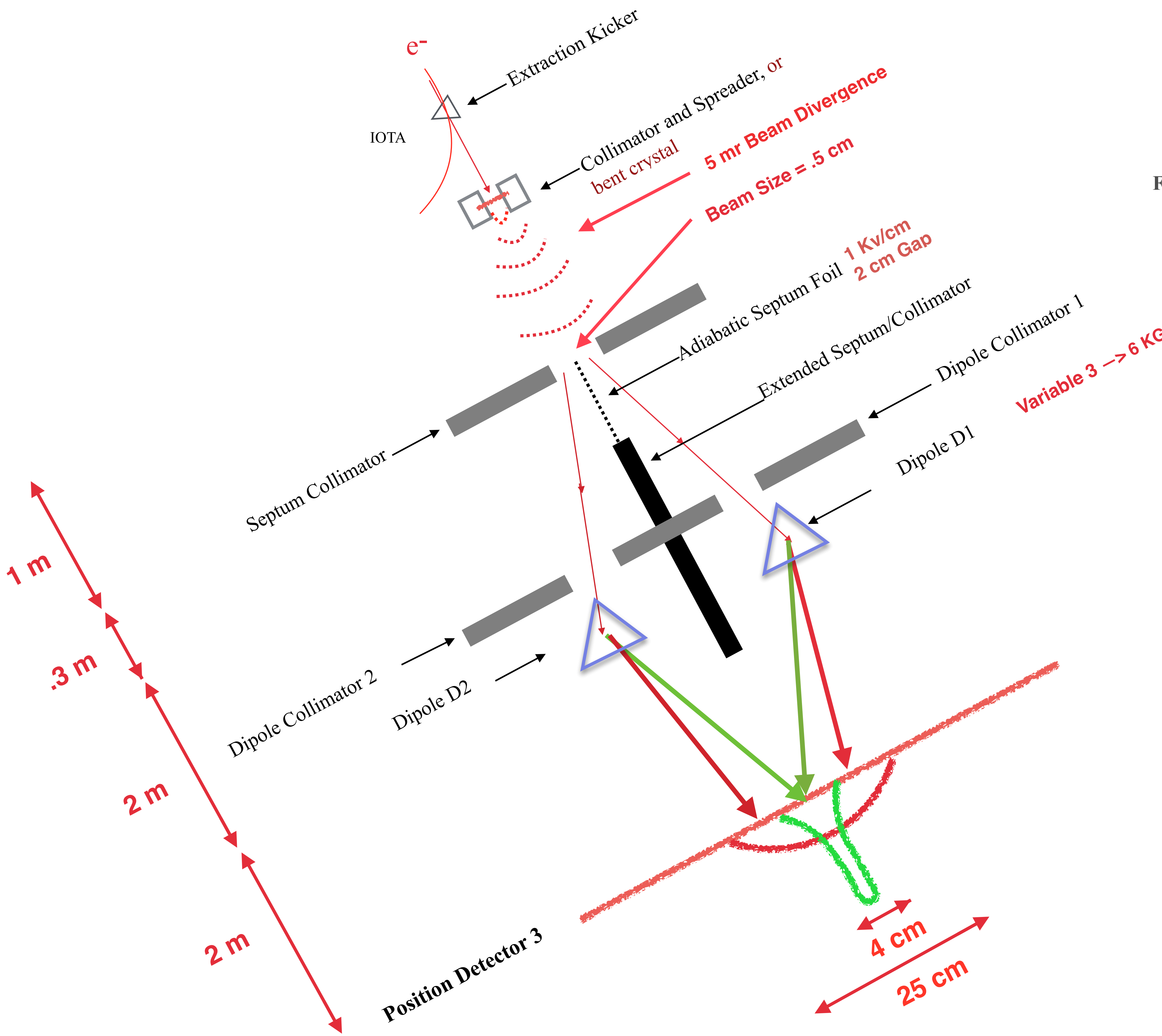
Enter TEDSE

- Attempt to see the same effect in using a very different technique
- Split wave function of electrons from IOTA or
  FAST on an electrostatic septum (Established technology at Fermilab)
- Beam energy 10 to 50 MeV
- Measure position and spread wave function as it enters the apparatus up stream of the septum
- Split beam on the septum (and, perhaps, the wave function)
- Send split “beam” through two spectrometers and measure position at the downstream end of the apparatus

$$\mathbf{F_L} = q[\mathbf{v} \mathbf{x} \mathbf{B} + \mathbf{E}] \int dx\, \boldsymbol{\Psi}^2_L(x)$$

$$\mathbf{F_R} = q[\mathbf{v} \mathbf{x} (-\mathbf{B}) - \mathbf{E}] \int dx\, \boldsymbol{\Psi}^2_R(x)$$





$$F_L = q[\mathbf{v}\times\mathbf{B}+\mathbf{E}] \int dx\, \Psi^2{}_L(x)$$

$$F_R = q[\mathbf{v}\times(-\mathbf{B})-\mathbf{E}] \int dx\, \Psi^2{}_R(x)$$

Simple, Fast Simulation

Detector (simulation) coordinate system:

- beam defines z axis, y is up, x for right handed coordinate system
- origin is target (scatterer) upstream face center

Units:

- distance (m)
- energy, momentum, mass [E,pc,mc^2] (MeV)
- time (s)
- electric field (MV/m)
- magnetic field (T)
- charge (e)

Particle generation and propagation (Root macro):

- random processes assumed Gaussian (beam momentum, position) unless otherwise noted
- particles propagate in vacuum except at target (multiple scattering only)
- scattering in target only (Gaussian)
- particles stop on hitting wall or aperture (no radiation, scattering)

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TEDSE Aparatus: Preliminary Design (1)

Unit Charge Electrons

Red lines are particle paths

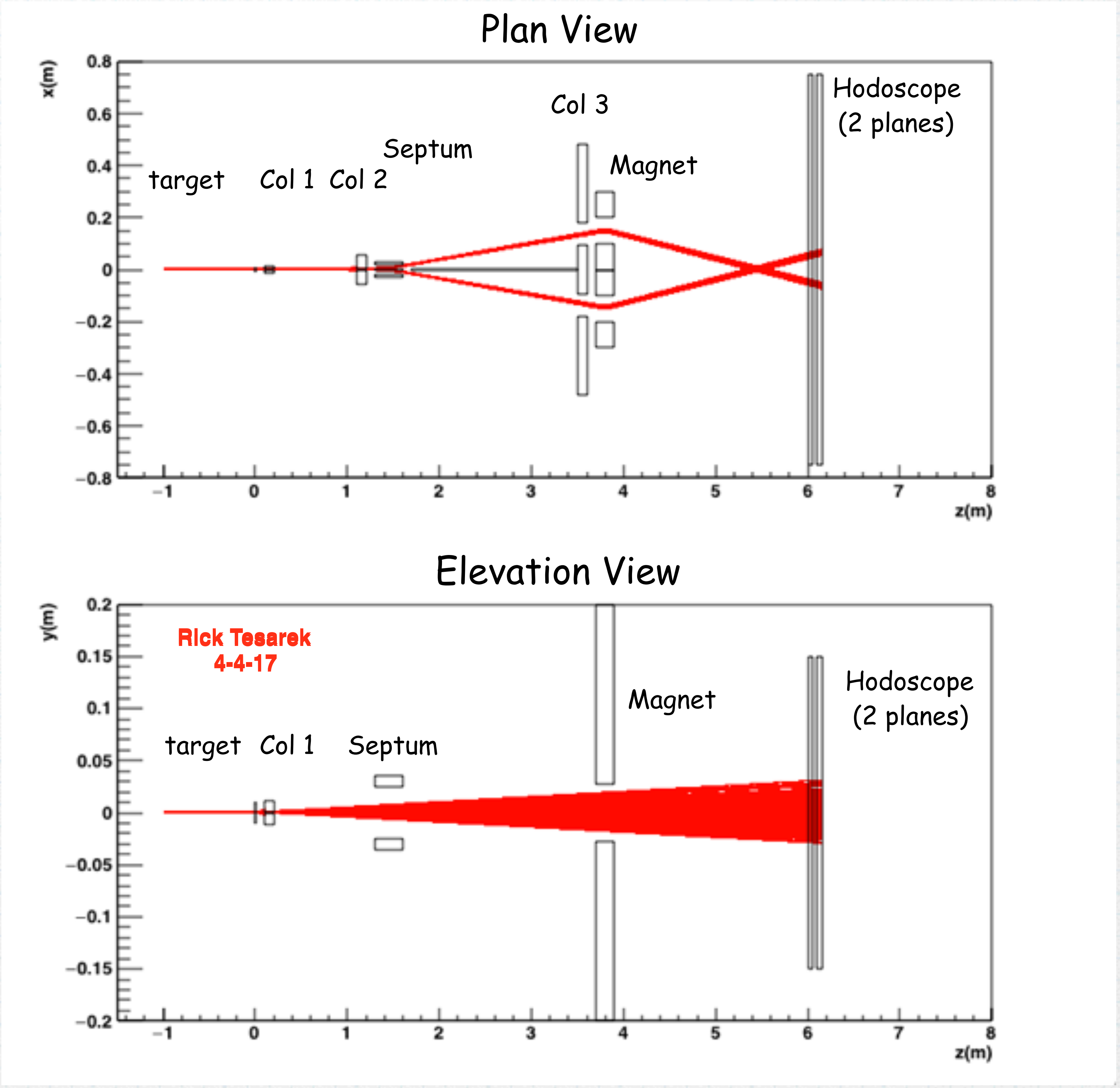
Small modifications to concept:

- 200μm thick diamond target
- 10 cm between elements
- Collimator 1:
  pin hole (2mm X 2mm)
- Septum full 10MV/m
- Magnet full 0.128 T

Observations:

- Unit charge electrons through septum/magnet
- Can't adjust septum to reach outer magnet aperture (full field)
- Over focused at hodoscope

NB: Note different transverse scale for Plan (horizontal) vs Elevation (vertical)



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Fractional Charges

Focus both arms on hodoscope 1 for narrowest image for integer charge events.

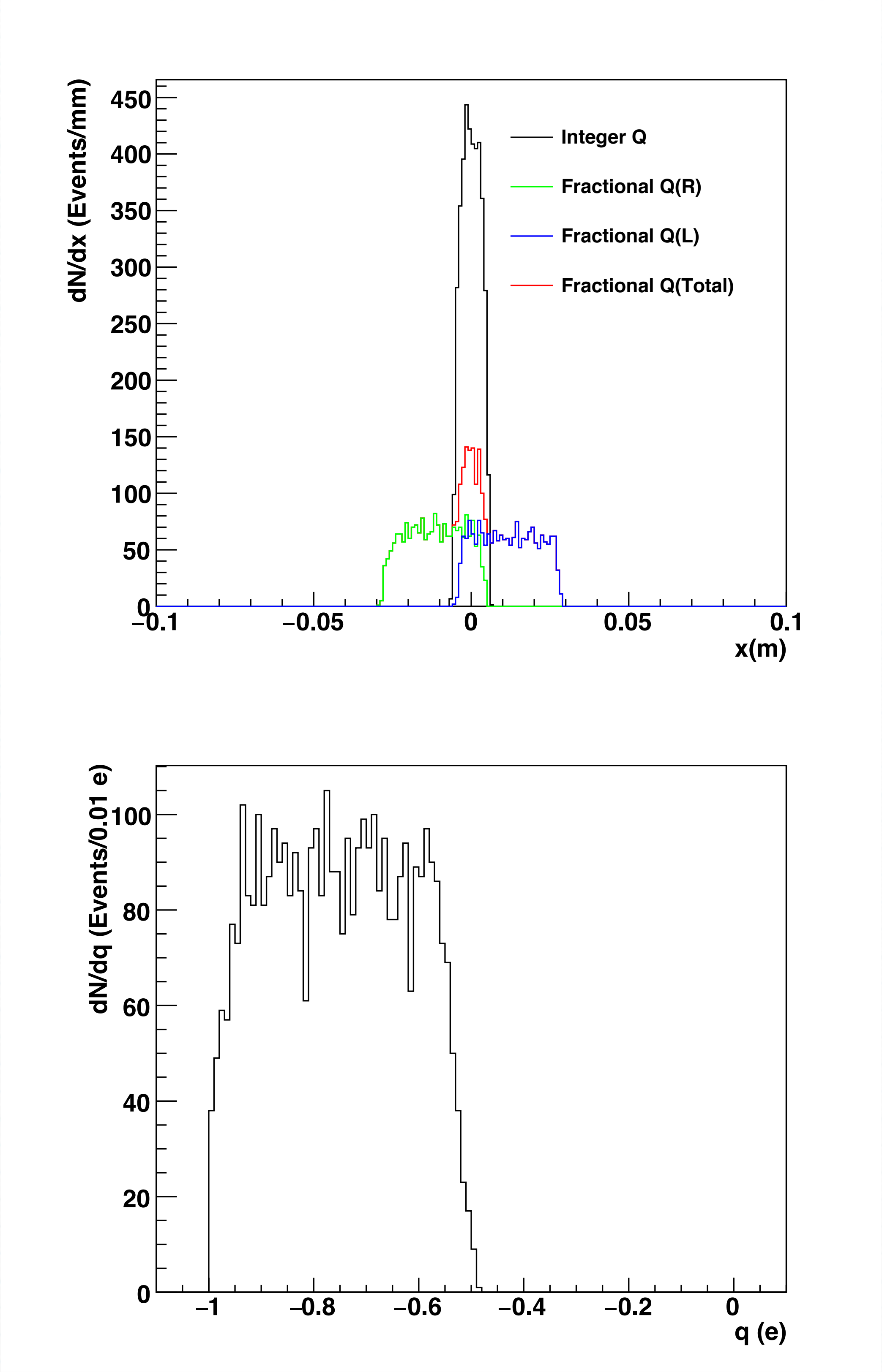
Modified layout:

- Substantial difference integer and fractional charges.
- fractional charge acceptance range -1.00 < Q < -0.55
- adjust E in septum to reach Q > -0.55

NB: signal on hodoscope within +/- 5cm (small detector)

Challenges:

- ➡ ΔV across septum = 400kV
- ➡ Understand identification of Q near -1



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TEDSE Preliminary Design (2)

Keep upstream section

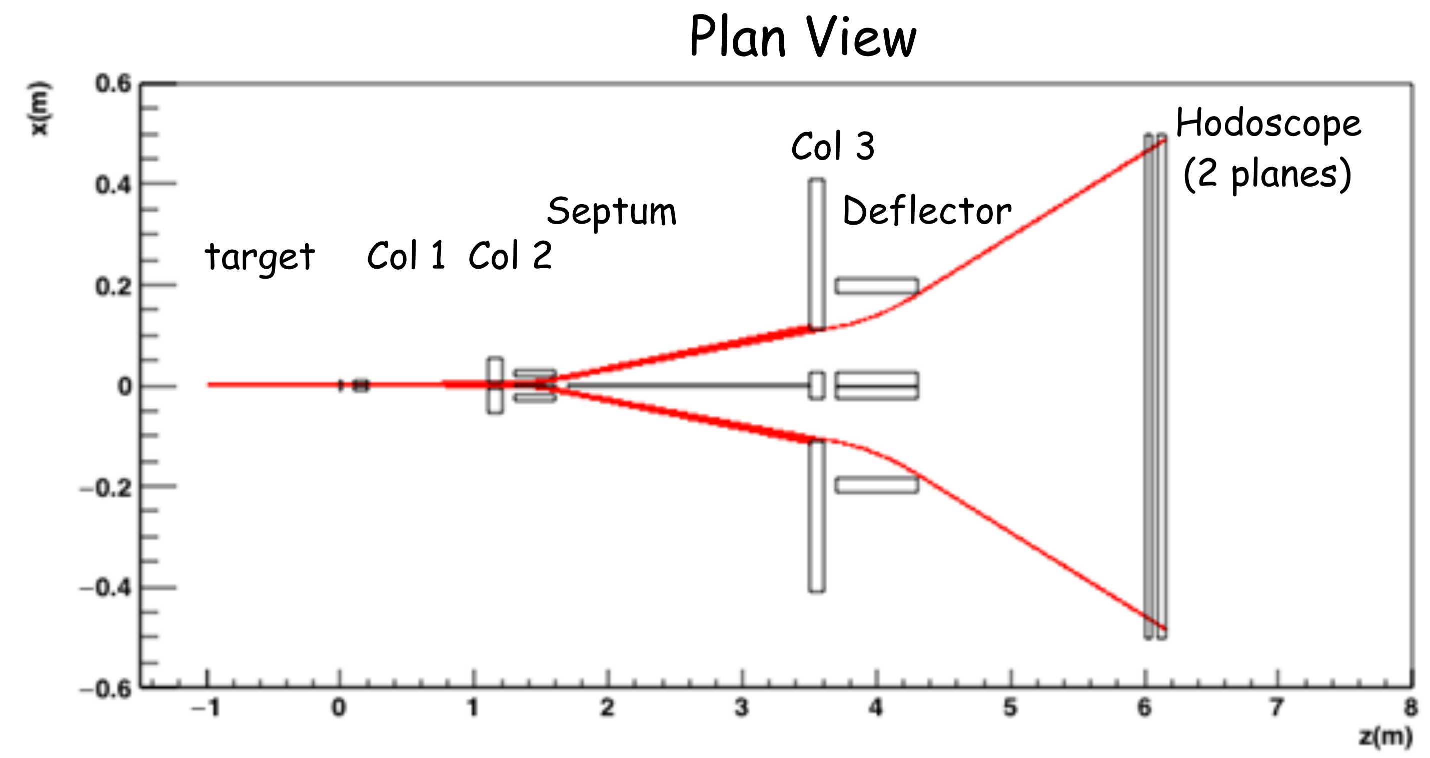
- target
- collimators 1,2
- reduce septum length to 30cm (same max field)

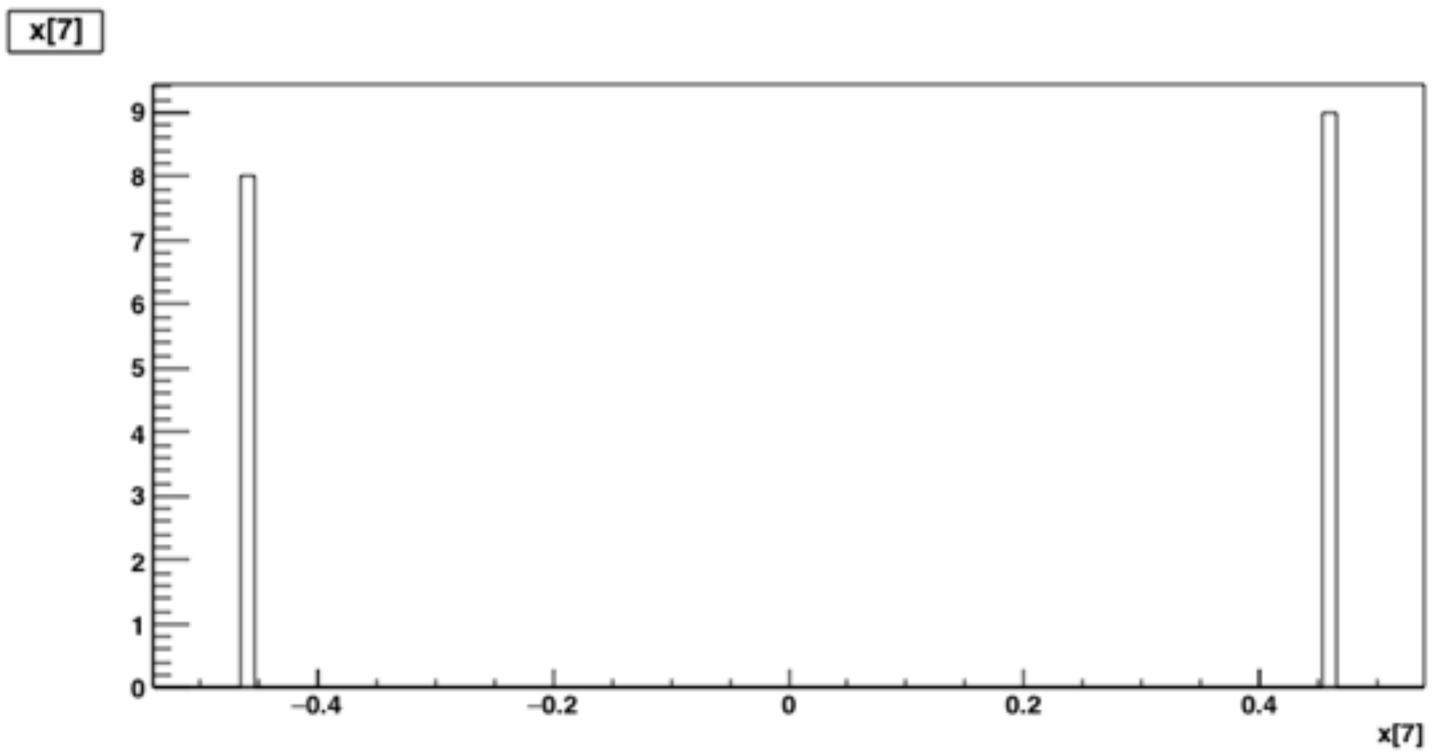
Use electrostatic deflector instead of magnet

- 60cm long, 16cm wide apertures (50% wider than magnet)
- modify collimator 3 to protect deflector plates
  ➡ less transverse distance between deflectors (smaller transverse kick by septum)

Hodoscope Dimensions

- Δx = 100 cm
- Δy = 10 cm





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Fractional Charges: Design (2)

Focus both arms on hodoscope 1 for narrowest image for integer charge events.

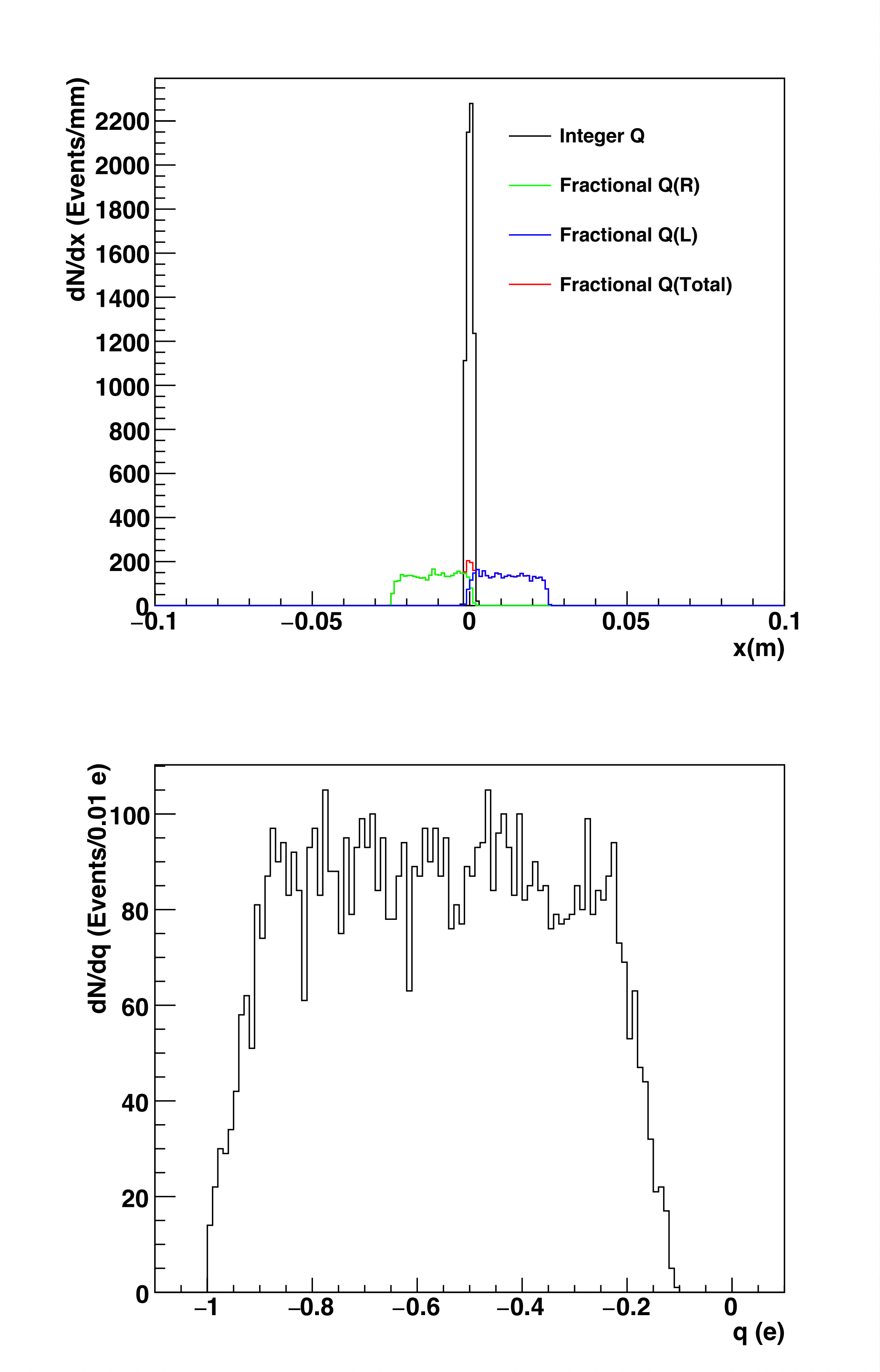
Deflector layout:

- Substantial difference integer and fractional charges.
- fractional charge acceptance range ~-1.0 < Q < -0.20
- adjust E in septum to reach Q > -0.20

NB: signal on hodoscope within +/- 3cm

Challenges:

- ➡ ΔV across deflector = 1,600kV (lengthen deflector, move deflector upstream?)
- ➡ Understand identification of Q near -1



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Summary

Two Preliminary Designs (Table):

- both satisfy basic physics goals

Magnetic Deflection:

+ magnets in hand
+ only 1 special (>100kV) HV supply
• limited fractional Q acceptance*
- longer/wider apparatus
- large hodoscopes
- magnets outside vacuum(?)

Electrostatic Deflection:

+ shorter/narrower apparatus
+ shorter/narrower apparatus
+ good fractional Q acceptance*
- large deflector HV
- 3 special (> 100kV) HV supplies
- Build deflectors ($$/time)

Both designs satisfy basic physics goals, but neither is "optimized"

Design	length (m)	Width (m)	Septum Aperture (m)	Septum length (m)	Septum HV (kV)	Magnet Aperture (m)	Magnet Length (m)	Deflector Aperture (m)	Deflector Length (m)	Deflector HV (kV)	Fractional Q Acceptance (e)*
1	7.65	0.30	0.04	0.60	400	0.10	0.20	-	-	-	-1.0 : -0.55
2	6.10	0.20	0.02	0.30	200	-	-	0.16	0.60	1,600	-1.0 : -0.20

* Fractional Q acceptance may be tuned!

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Implications of a Positive Signal

- Operating on a single wave function in two separate spaces has implications for the interpretations of quantum mechanics
  - Quantum Measurement
  - The physical reality of the wave function — not just a probability distributions as per the Copenhagen Interpretation
  - Pilot waves, or DeBroglie/Bohn interpretation ruled out
  - Multiverse interpretation — wounded, but can never be killed

"My own conclusion is that today there is no interpretation of quantum mechanics that does not have serious flaws. This view is not universally shared. Indeed many physicists are satisfied with their own interpretation of quantum mechanics. But different physicists are satisfied with different interpretations. In my view we ought to take seriously the possibility of finding a more satisfactory theory, to which quantum mechanics is only a good approximation."

Steven Weinberg

Lectures on Quantum Mechanics

Chapter 3, p.102

2015

Summary of Results and Explanations

- **Experiment has been done many times in superfluid Helium with consistent results**
- **As experiments were refined more "Exotic Ions" (Fast Ions) became visible**
- **Only explanation put forward was that electrons were split between more than one bubble; such electrons were individually dubbed electrinos**
- **Photoconductivity experiments give consistent results; i.e., light at the proper frequency increases photoconductivity ⇒ increasing mobility of bubbles**
- **Mobility result is firmly established; interpretation is in question**
- **Many think superfluid helium is too complicated to understand; this does not apply to those working with it as evidenced by the large number of quantum calculations and correct predictions in the literature**
  - **Result has no completely independent confirmation that might aide the interpretation (up to now all measure mobility of bubbles in superfluid helium)**
  - **Conclusion: It is time to do an experiment that does not depend on Superfluid Helium**

Approval Process

- Proposal submitted to Program Office in late October
- Steve Sent it to Joe Lykken for comment — Joe was silent
- To trick Joe into reading it Sergei, Steve, and I set up a meeting with Joe on December 15
    - Joe had only skimmed the proposal before the meeting
    - He indicated that it was interesting and that we should just do it.
    - After he read it more carefully (my interpretation) he became more interested and said we should meet again on it. He was cautiously enthusiastic in the second meeting indicating we should find a way to do it

Wave Function Spreading

- Need? ≥ 1mm at electrostatic .001” septum foil
- Bent Crystal provides this by means of the Uncertainty Principle
- Multiple Scatter might also do the job, but no one feels good about this
- No one really understands this

Dipoles and Collimators

- Dipoles should run at both polarities to study backgrounds and signal
- Collimators must move independently to allow one aperture open at a time