Progress in the Sydney University Polywell Project

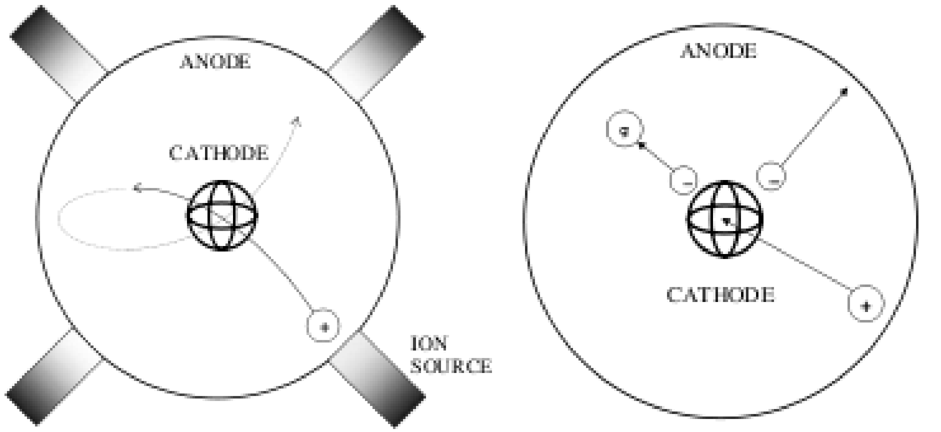
Potential Well Formation | Confinement | Magnetic Field Structure

Matthew Carr | PhD Student
Supervised by Dr Joe Khachan

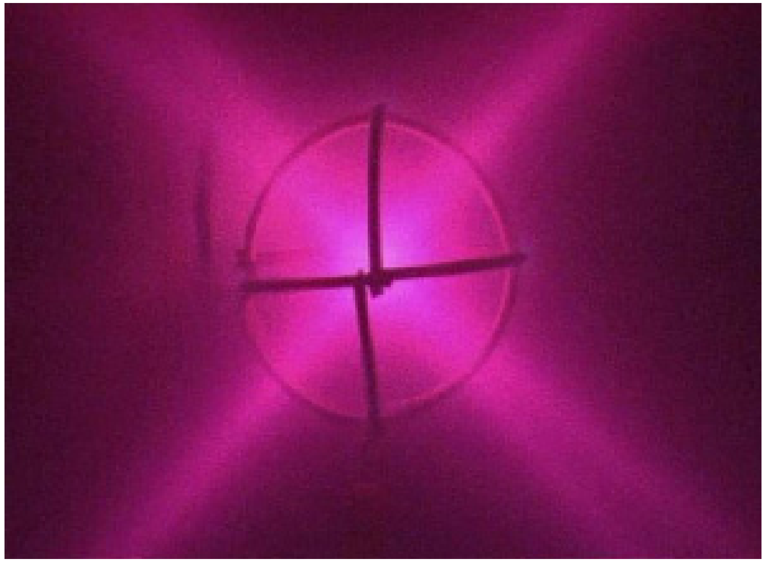
THE UNIVERSITY OF SYDNEY

Motivation for the Polywell

- Gridded IEC devices experience heavy loses through ion collisions with the grid.
- Over many cycles passing through the grid, ions are eventually likely to collide with the grid, both loosing energy and heating the grid to impractical levels for steady state fusion.



(a) Farnsworth-Hirsch fusor (b) IEC in gaseous discharge mode

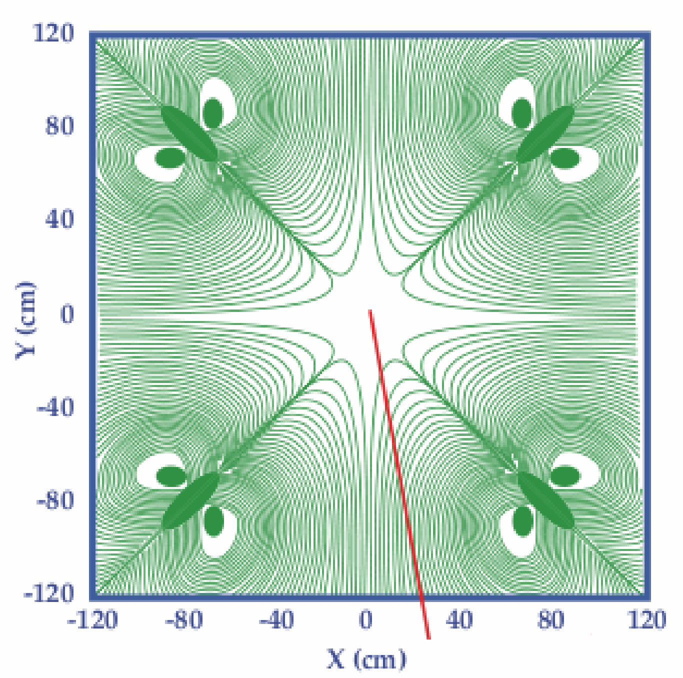


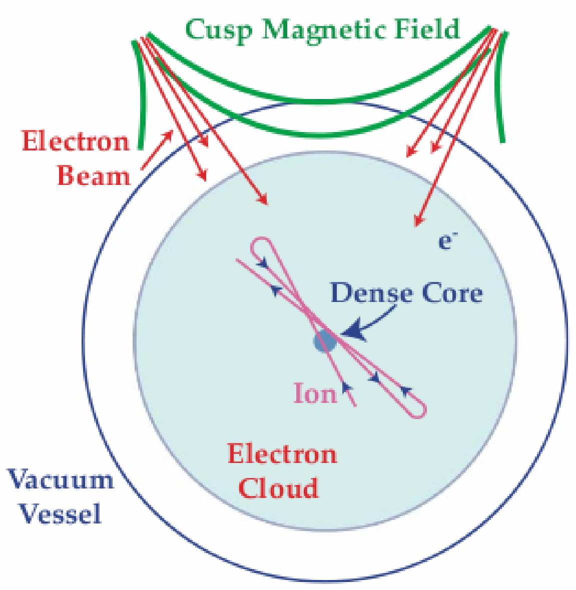
The Magnetic Field Concept

› Use large magnetic fields in addition to electrostatic grids to create a virtual cathode.

› Field created by pairs of opposing current loops, each creating a cusp about the origin.

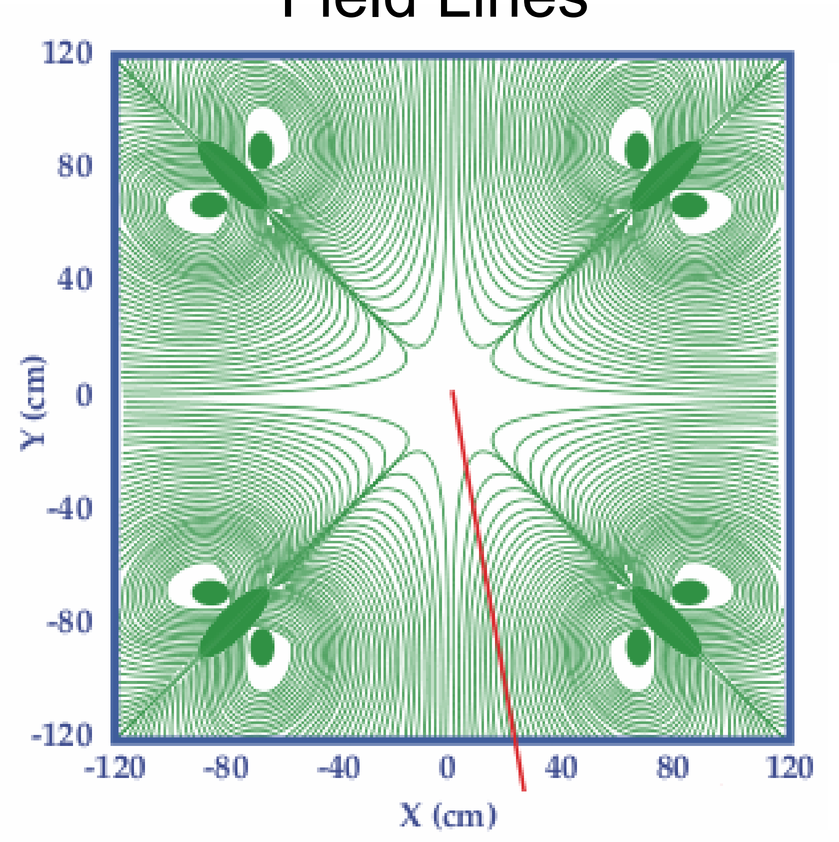
› Magnetic fields vanish in centre due to symmetry creating a null point.



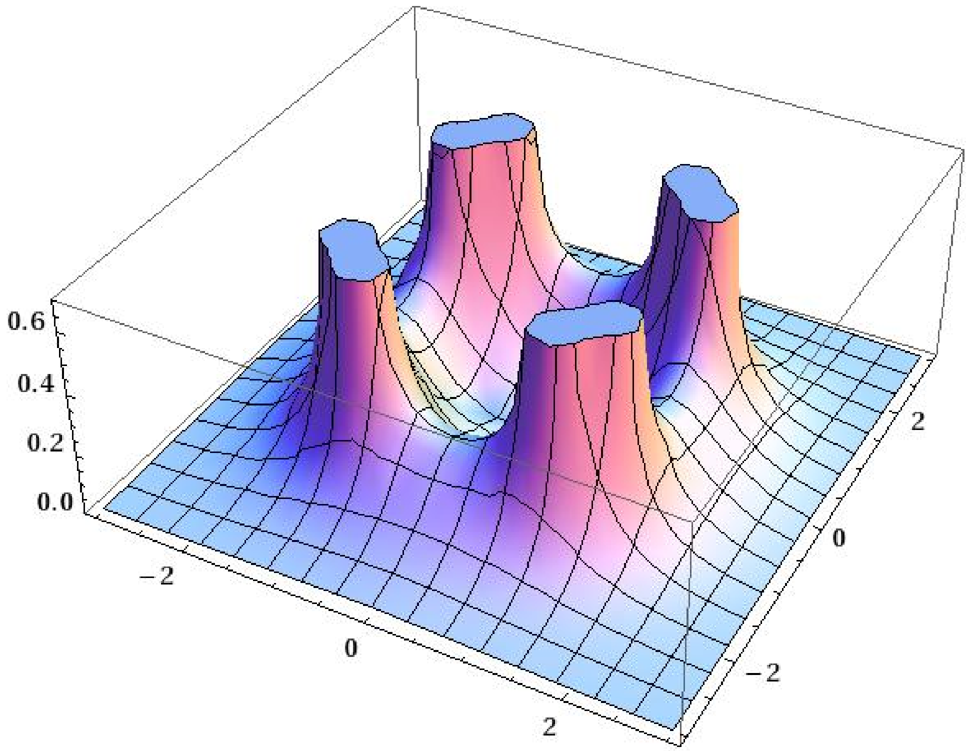


Magnetic Field Structure

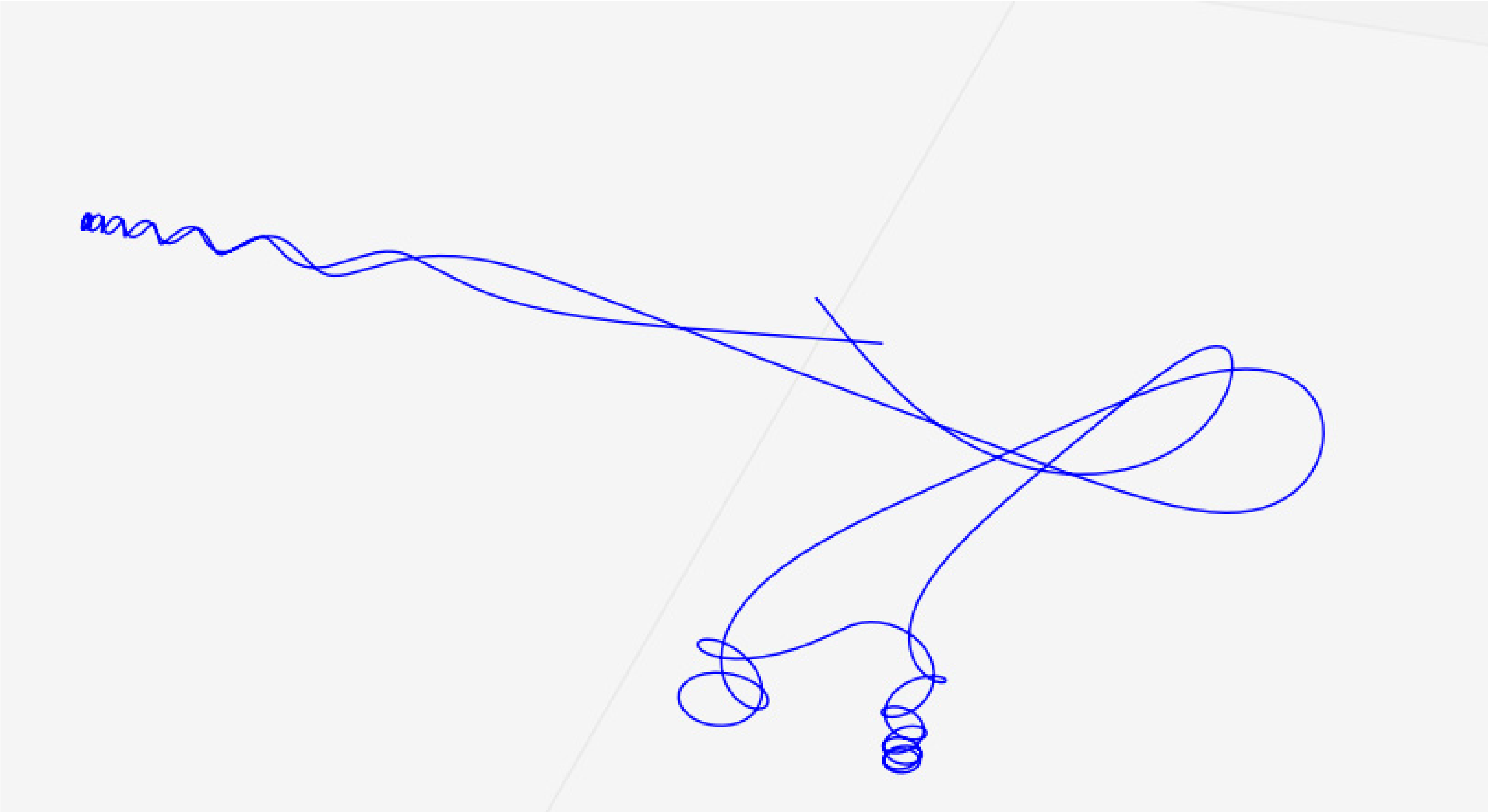
Field Lines



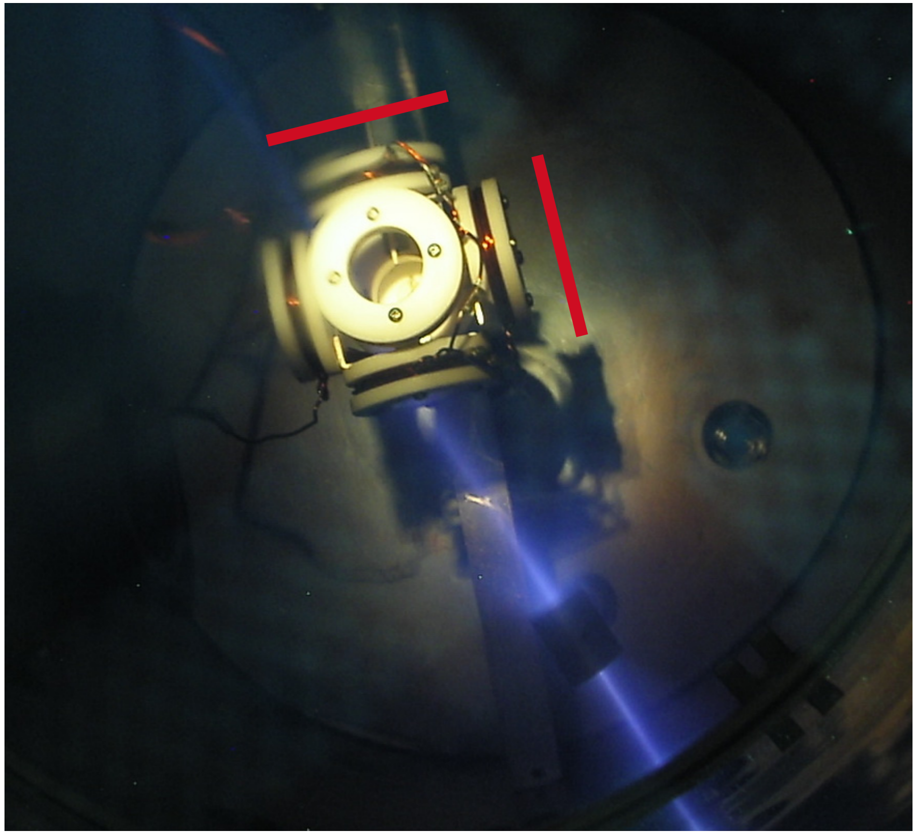
Absolute Magnitude of B



Single Electron Trajectory Simulation

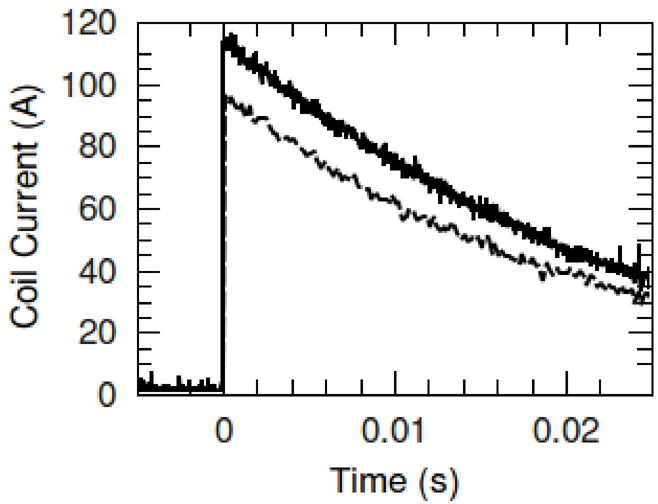


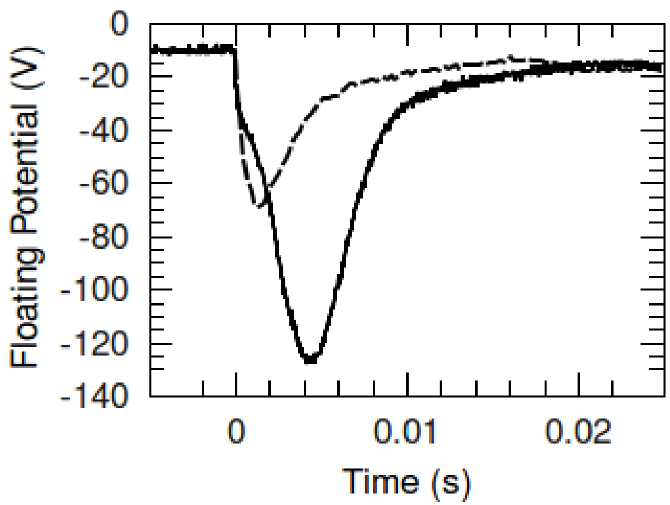
Experimental Setup



- 60mm diameter
- 10 copper wire turns in each coil
- Electron beam provided by cylindrical cathode
- Langmuir probe for measuring floating potential
- Collector plate positions shown in red

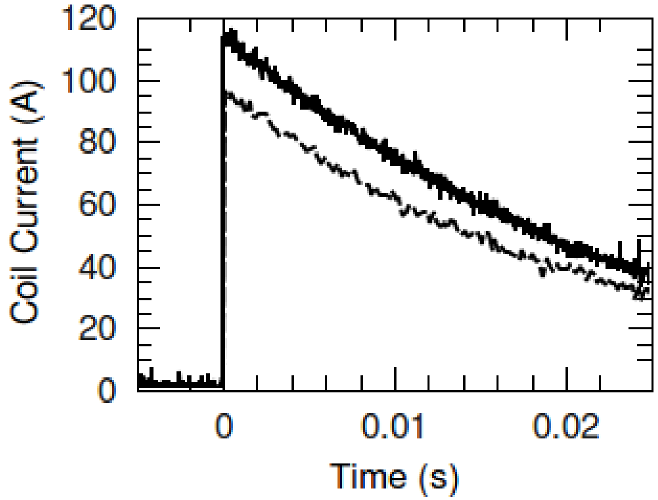
Two Example Potential Well Measurements

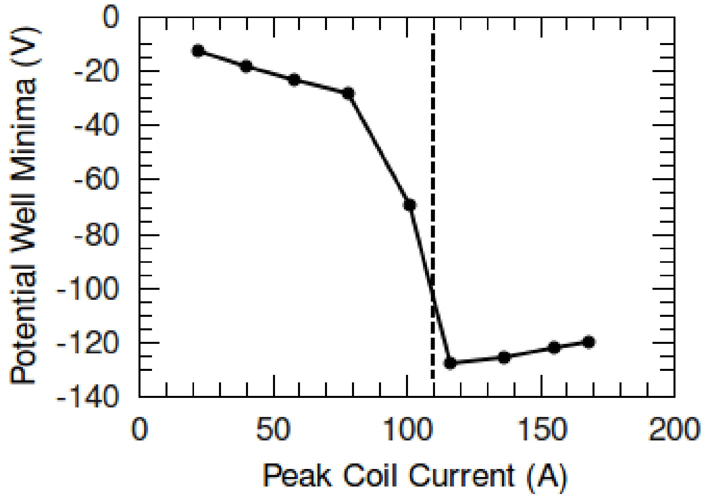


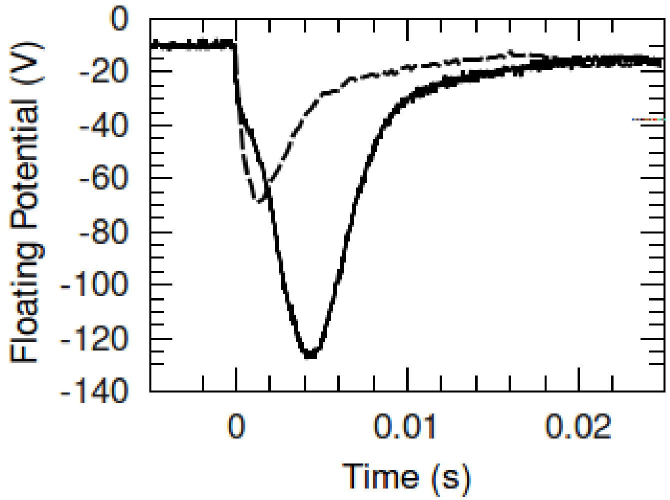


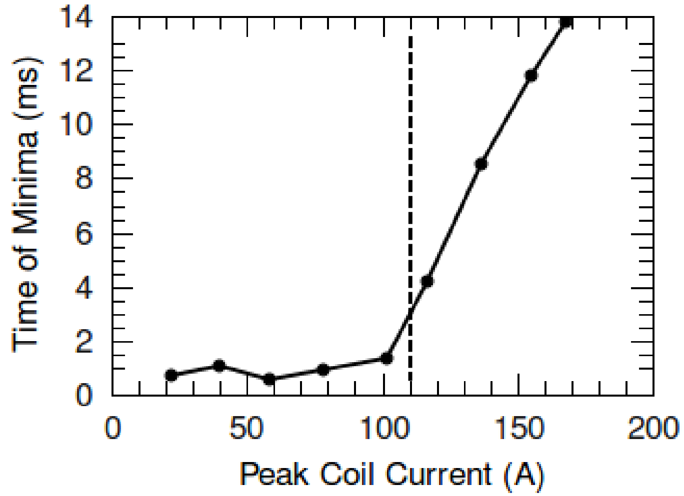
- Each current pulse in top figure has a corresponding potential well profile on the bottom figure.
- There is a big difference in the potential wells measured for small changes in current.
- This is a very dynamic system, may not have reached equilibrium.
- Behavior as a function of magnetic field strength is not straight forward.

A Wider Range of Current Pulses





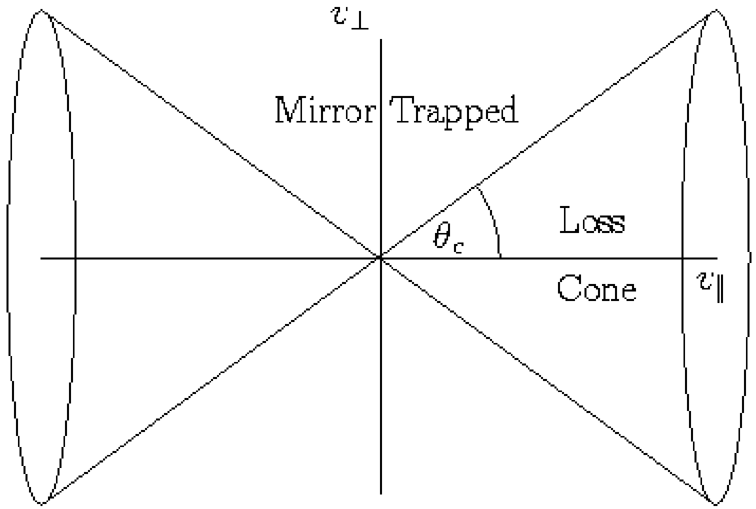




Explanation – The Magnetic Mirror Effect

- The magnetic mirror effect and its applications to fusion is based on the adiabatic invariance of the magnetic moment μ
- μ is a constant of motion if the spatial variation in the magnetic field B is small with respect to a complete cyclotron orbit.
- Condition for reflection in a magnetic mirror is approximately dependent on the ratio of the relative magnetic field strengths

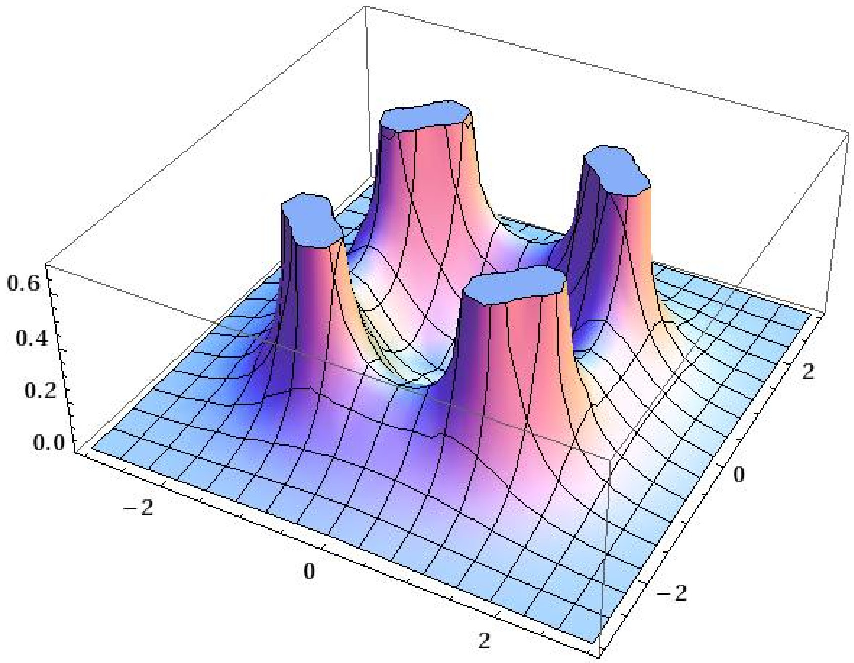
$$\frac{B_0}{B_m} = Sin\,\theta_m$$



- B_0 is the minimum of magnetic field
- B_m is the maximum magnetic field at the centre of the coils
- θ_m defines a loss cone in phase space. Particles with velocity inside this cone are lost from the system

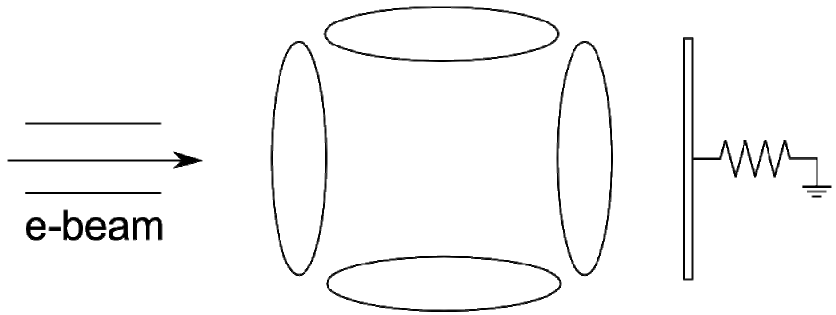
Reflection of the Injected Electron Beam

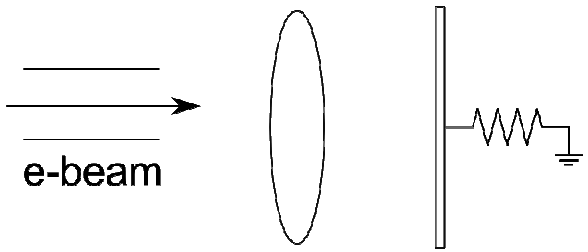
- The mirror ratio is only dependent on a difference between the magnetic fields and hence there is also a magnetic mirror outside the Polywell.
- A fraction of the injected beam with velocities outside the loss cone are reflected from the Polywell faces.
- This idea predicts that there will be a threshold point where a potential well can no longer form since a substantial portion of the injected electron beam is now reflected and no longer enters the device.
- The unique geometry inside leads to more reflections and better confinement.

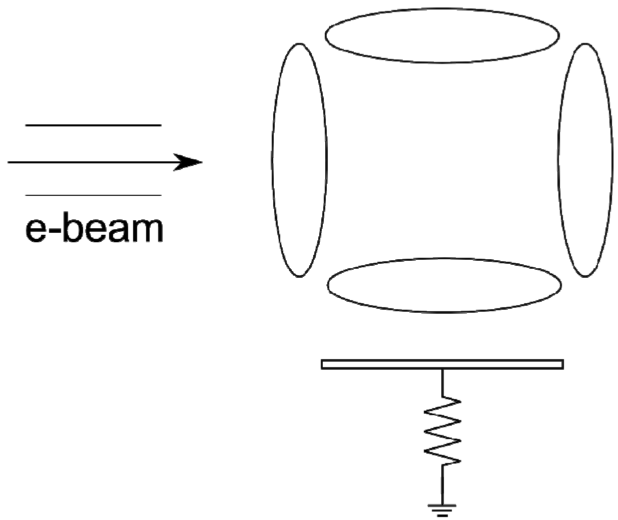


Collector Plate Experiment

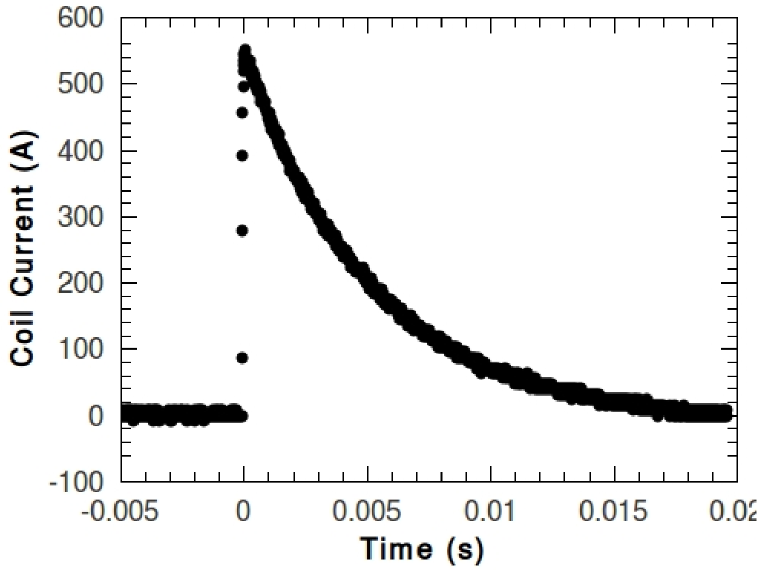
- Idea – lets measure the electric current arriving at the Polywell faces as a function of time. Measures the leakage rate of electrons from the Polywell.
- Effectively measures confinement
- Use single coil as test
- Measure face behind Polywell
- Measure one side of the Polywell

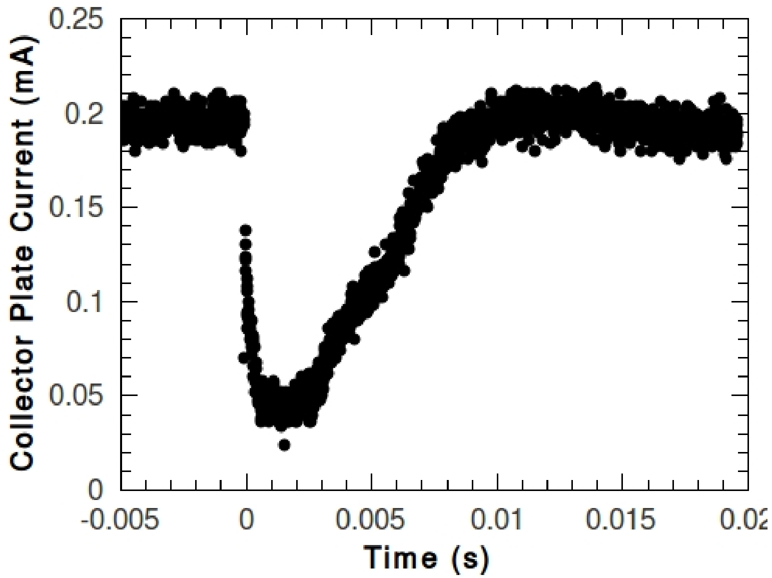


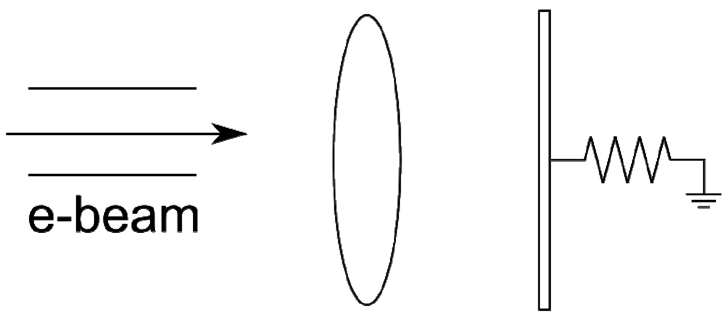




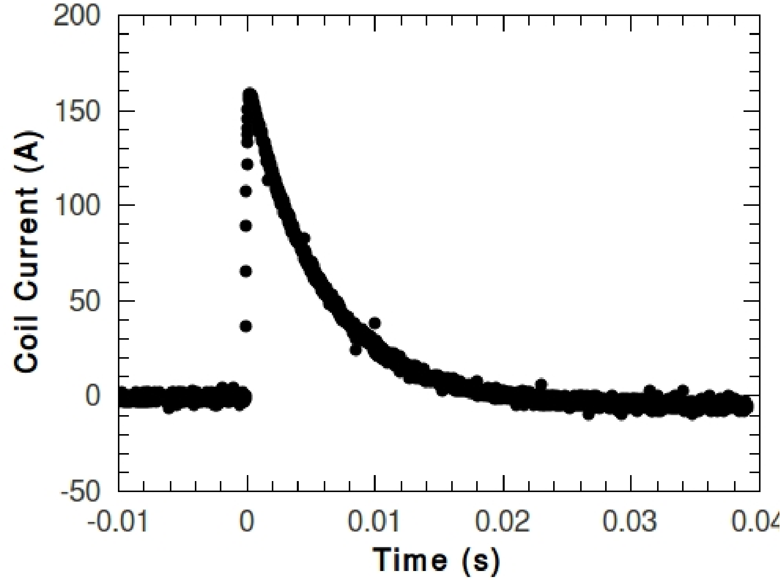
Collector Plate with Single Coil as Calibration

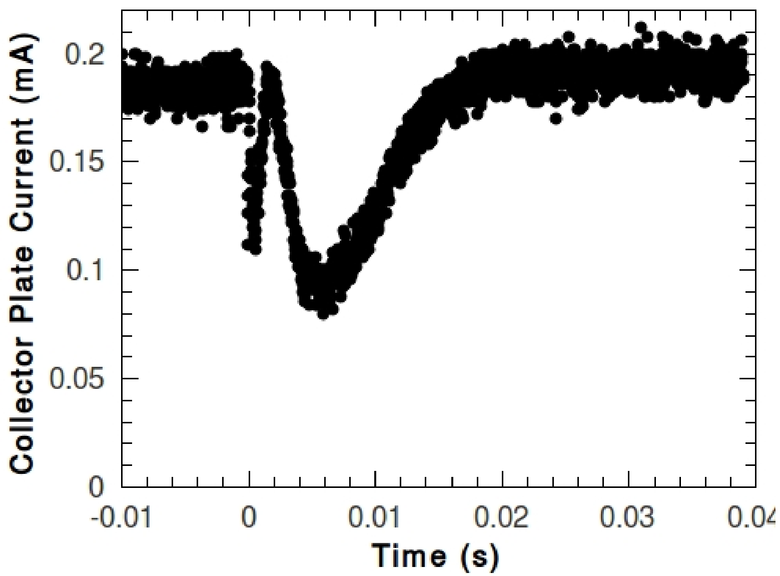


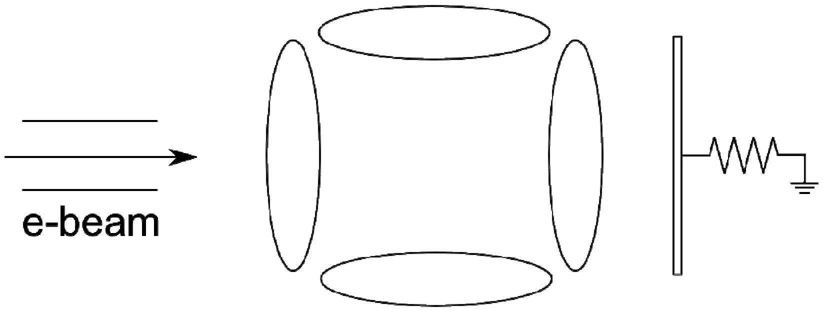


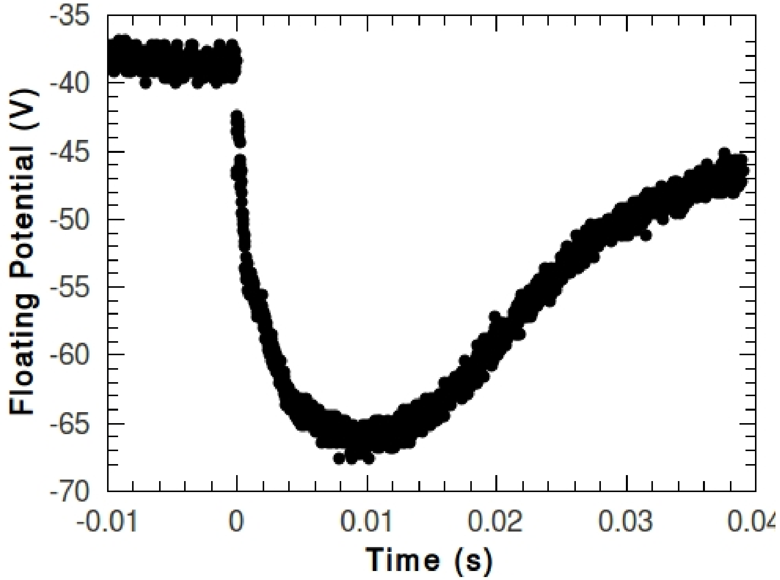


Collector Plate Behind the Polywell

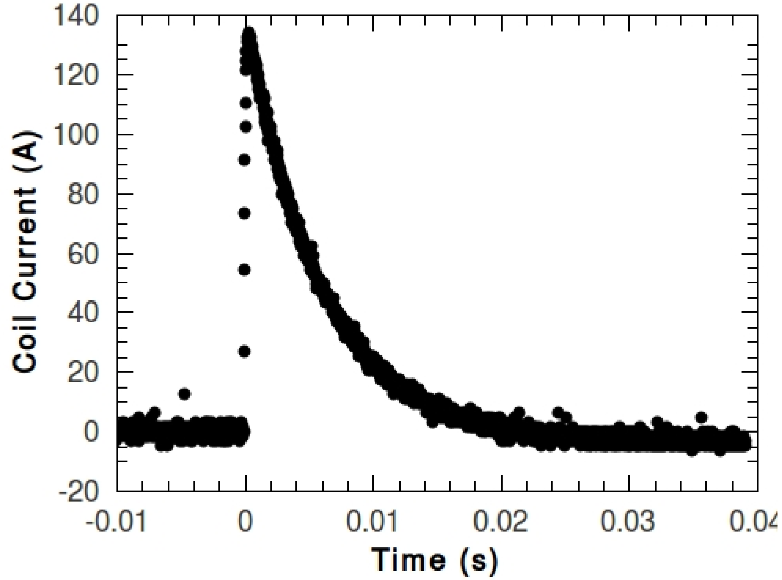


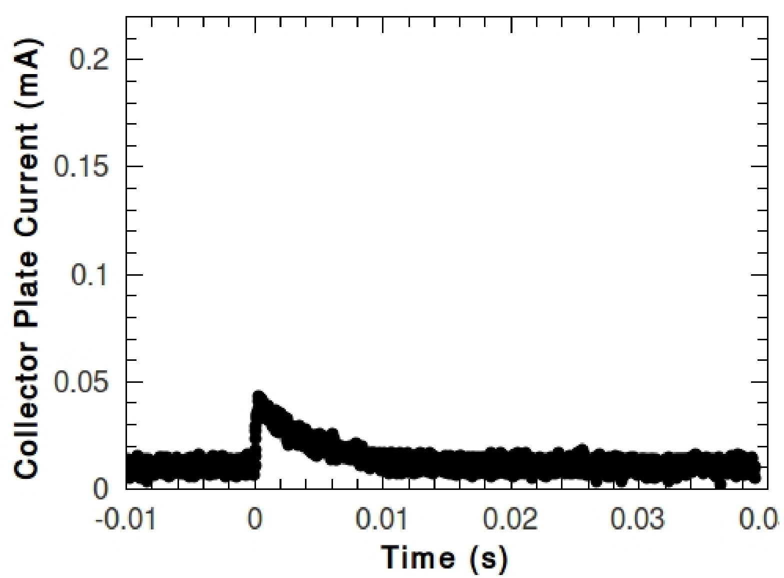


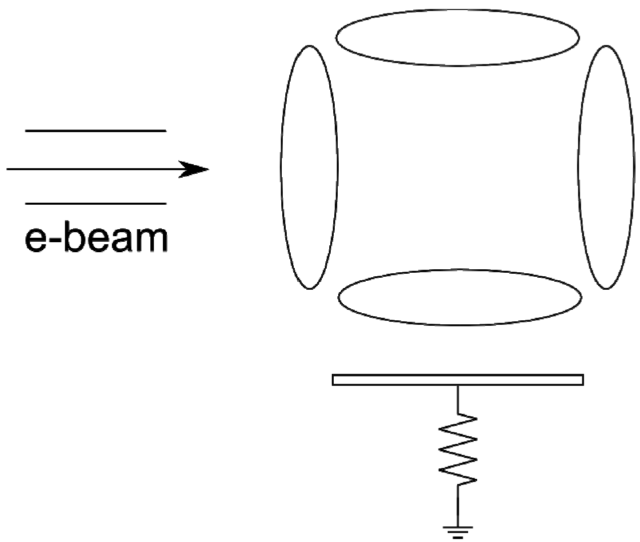


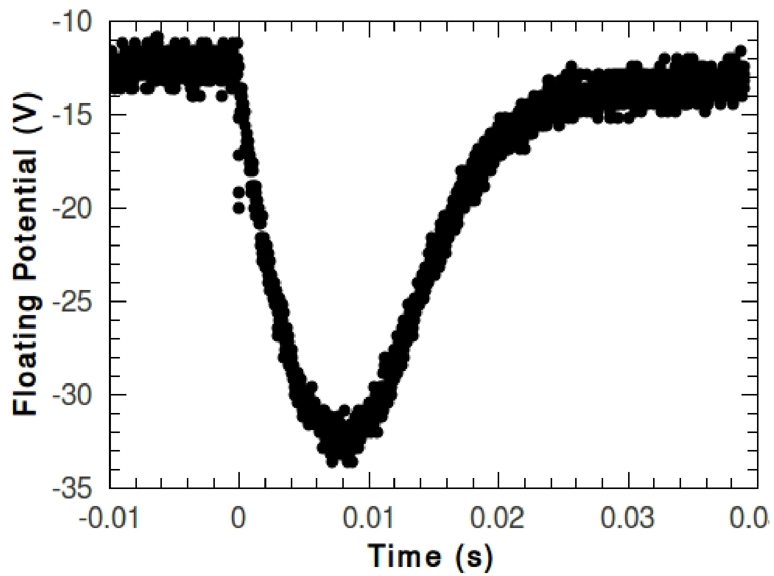


Collector Plate on Side Face of Polywell

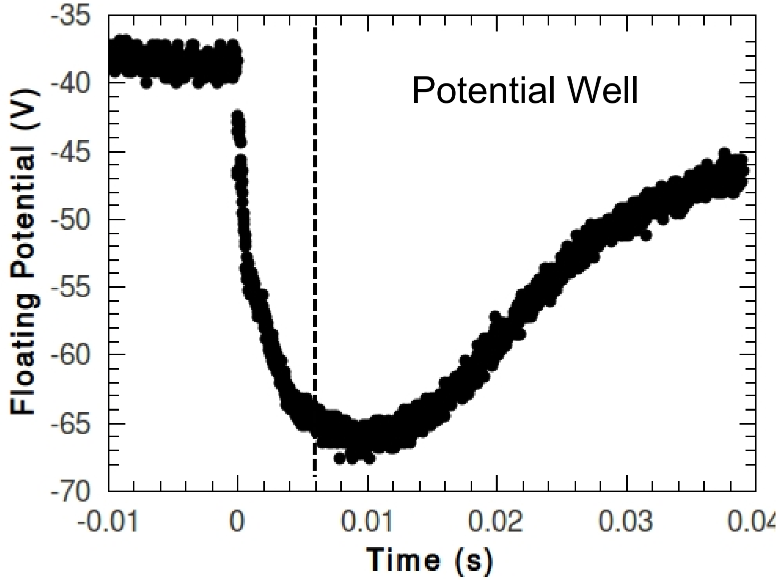


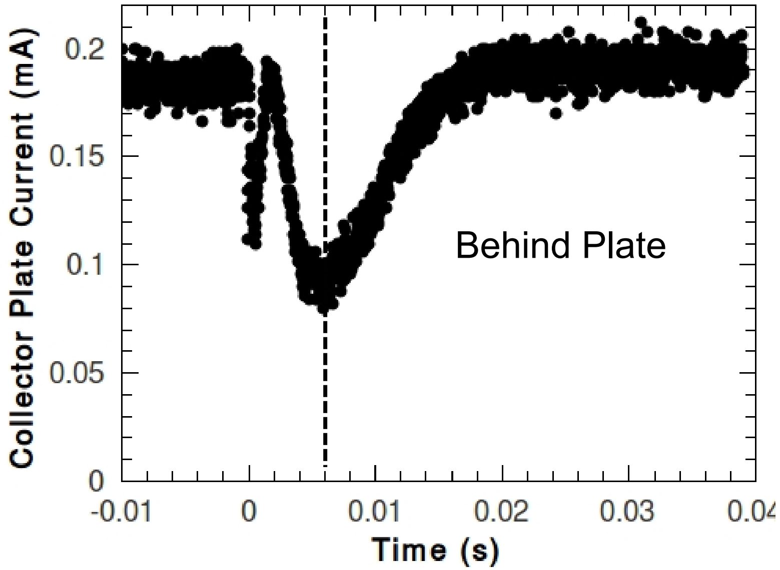




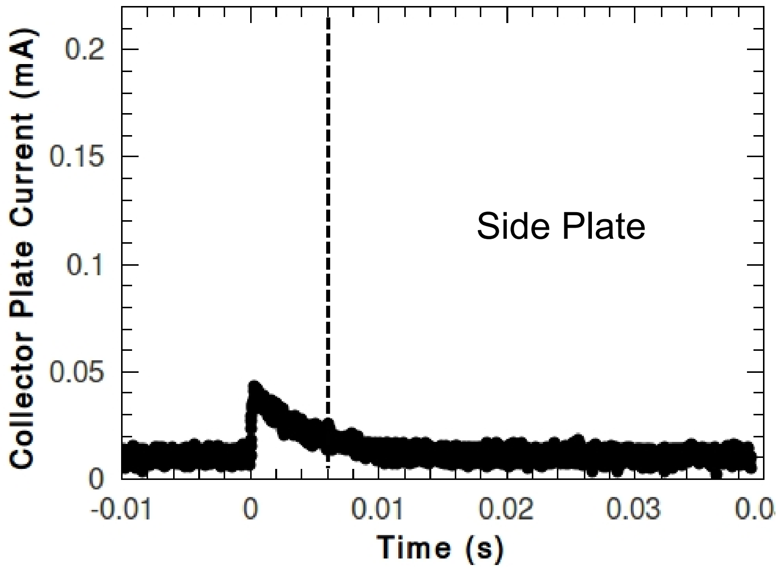


Putting all the Data Together



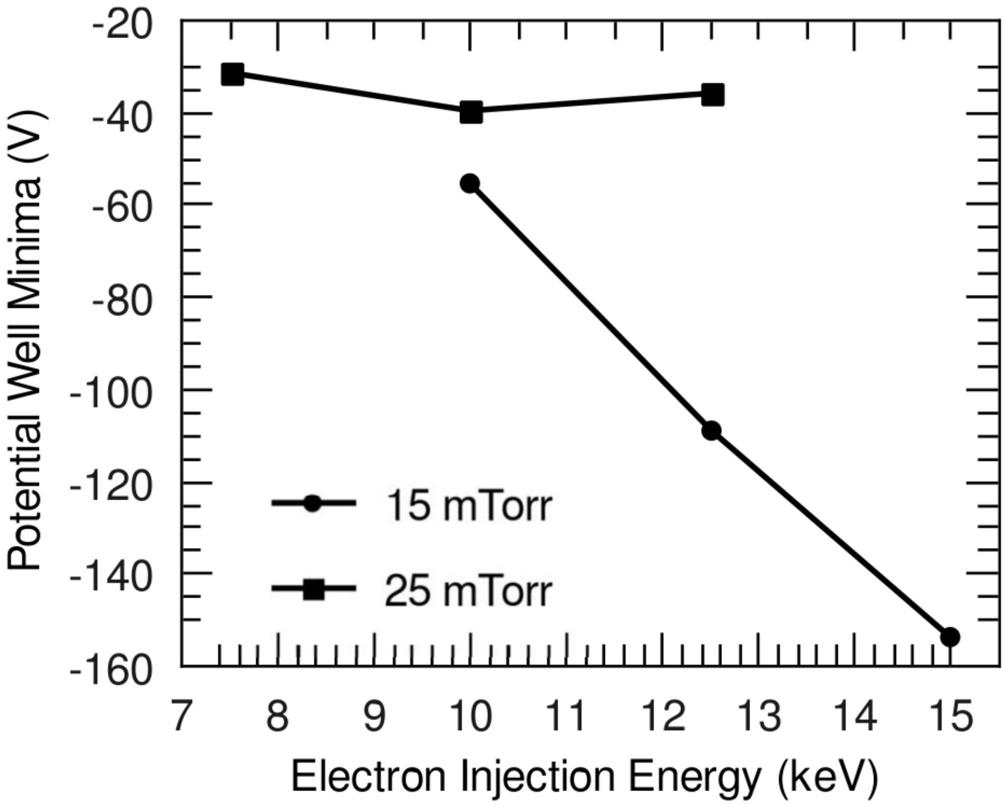


- At 6ms you have a minima in the current passing through the Polywell and negligible current leaking out the sides.
- Is this evidence for confinement?



Well Depth VS Pressure and Injection Energy

› Well depths as a function of electron injection energy at constant magnetic field strength and varying background gas pressures.

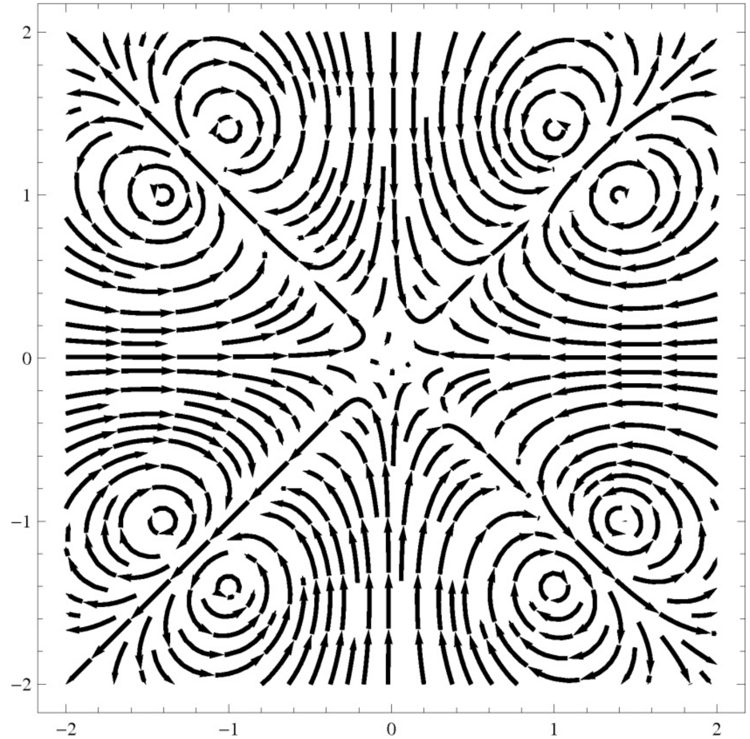


Implications of Pressure Dependence

- Because of the relatively high background gas density, neutral gas is being ionised by the incoming electron beam and the newly created ions decrease the potential well created by the electrons.
- At pressures of 20mTorr, the ionisation mean free path is 5m.
- Electrons were trapped for many milliseconds in the Polywell core. The distance they travel is much larger than the mean free path.
- Therefore the production of ions by the trapped electrons must be considered as a mechanism for reducing the well depth.

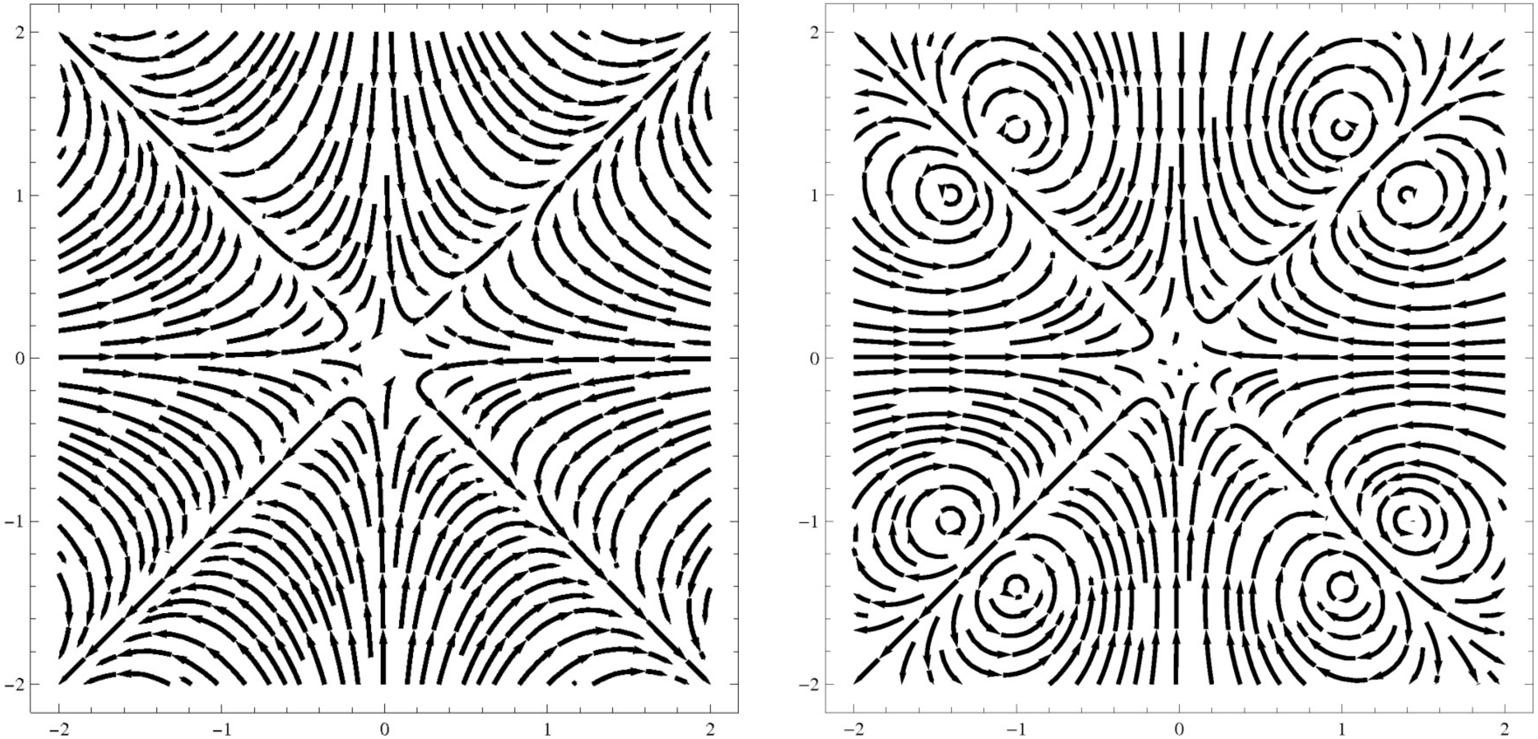
Magnetic Field Equations

- Break the problem up in to 3 parts. 3 pairs of opposing coils, with each pair centred on a Cartesian axis.
- Use the expressions for a single coil, and add them for each pair with a sign change and position offset.
- For the overall problem, add the contributions from each pair.



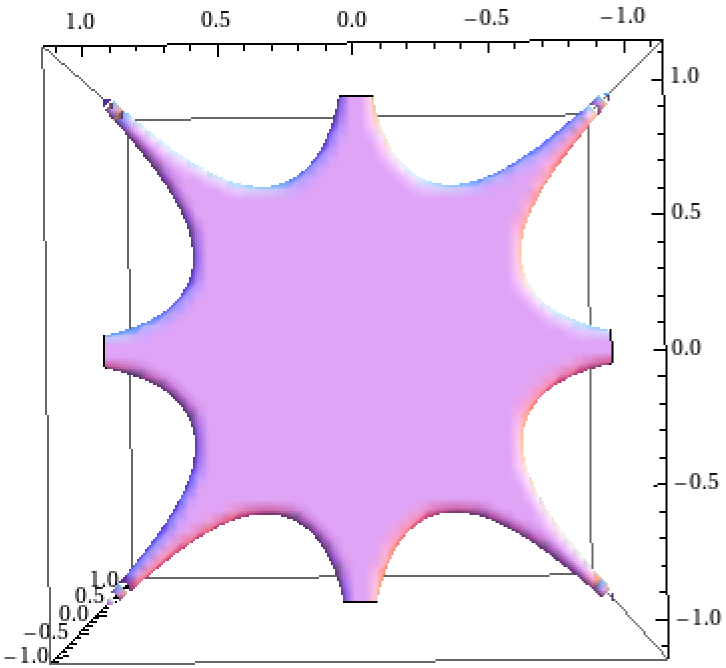
Central Well Approximation

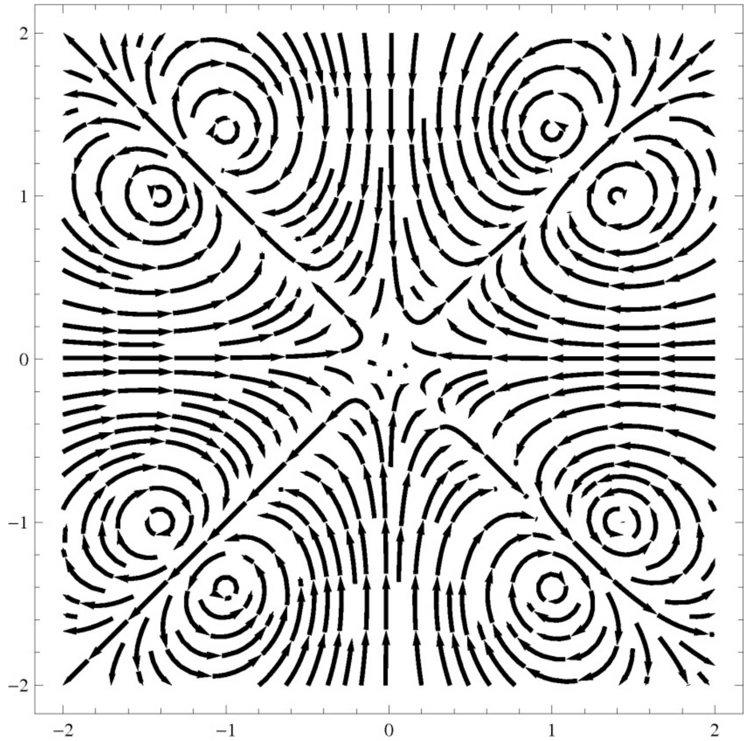
$$\vec{\boldsymbol{B}} = \frac{35\mu_0 I}{128\sqrt{2}a^4}\left((-2x^3+3x(y^2+z^2))\vec{\hat{\boldsymbol{x}}}+(-2y^3+3y(x^2+z^2))\vec{\hat{\boldsymbol{y}}}+(-2z^3+3z(x^2+y^2))\vec{\hat{\boldsymbol{z}}}\right)$$



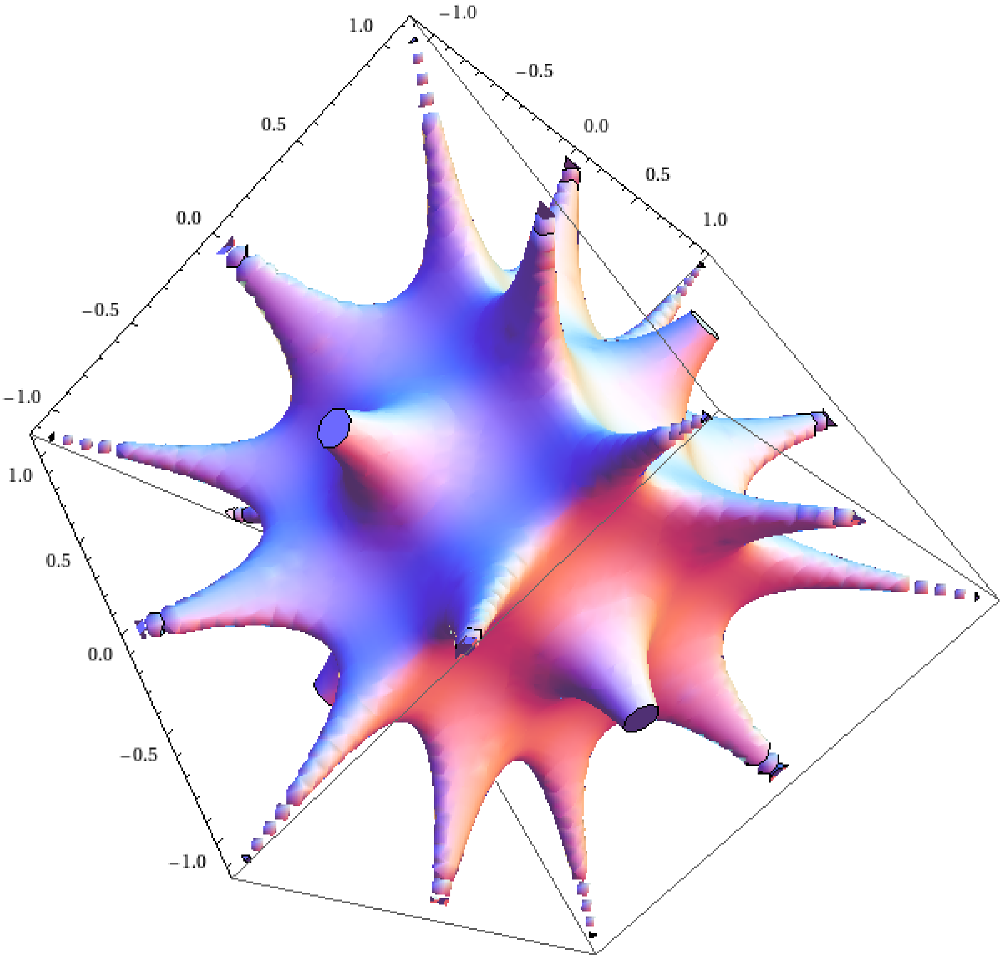
Cut-away of a Field Line Surface

- We would really like to see what the flux surface looks like in 3D.
- Pick a contour of constant magnetic vector potential A, and plot as a 3D surface.





Result – A Wiffle Ball?



Conclusions

- Virtual cathode formation has been observed through Langmuir probe measurements, stable on the millisecond timescale.
- A study of virtual cathode formation as a function of magnetic field strength reveals a threshold field above which potential wells no longer form.
- Collector plate measurements reveal that a low electron leakage mode can be observed coincident with the minima of the potential well.
- Theoretical work on calculating the magnetic field equations has resulted in a simple expression for the central well field of the Polywell.