Penning Traps as Neutron Sources

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Foreword

- Thanks to
  - Organizers
  - Tri Alpha Energy
- No neutrons were ever produced (detected) from this scheme
- Original concept – G. Miyamoto, G. Iwata, S. Mori, and K. Inoue, *J. Phys. Soc. Japan* (1957)

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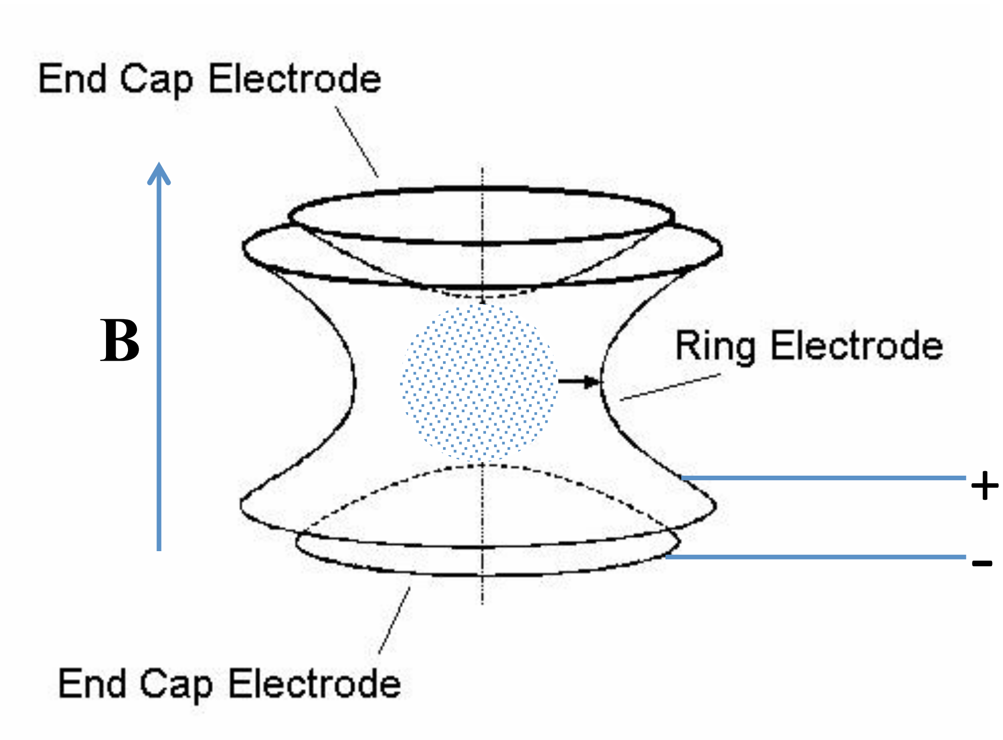
Scheme

- A Penning trap with uniform B, harmonic E can be tuned to make a spherical well for electrons (No grids)
- Electrons are maintained IEC beam-like by appropriate boundary conditions
- Spherical convergence produces a central virtual cathode
- Ions confined in the central cathode can reach keV energies and produce neutrons

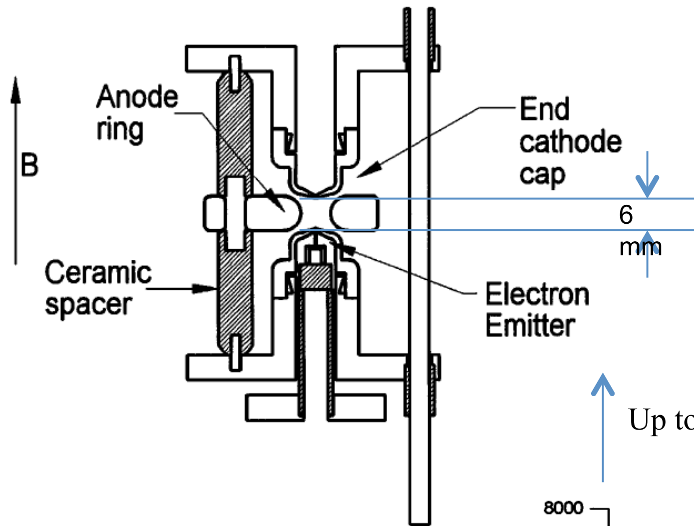
Penning Trap



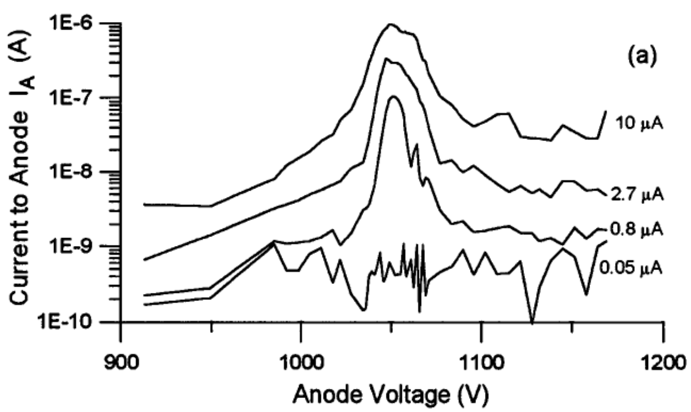
$$\Phi = \frac{2V}{3}\left(\frac{r^2/2 - z^2}{a^2} + 1\right)$$

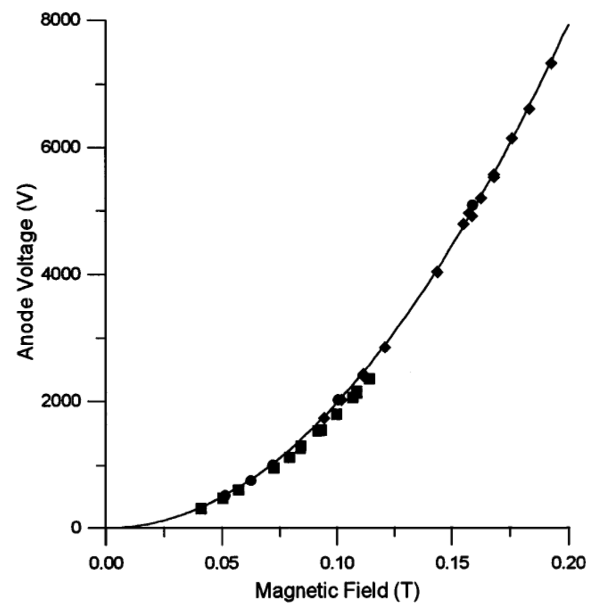
- Electrons "dropped" off low radius part of cathode see 3D well (zero angular momentum – Brillouin flow)
- Tuning V with B can make well spherical and harmonic
- Geometry is such that electrons don't hit anode
- Electrons are recollected at low energy at cathode

Cold-bore, spherical trap
PFX, LANL, 1997



Up to 30 kV w/o
heater





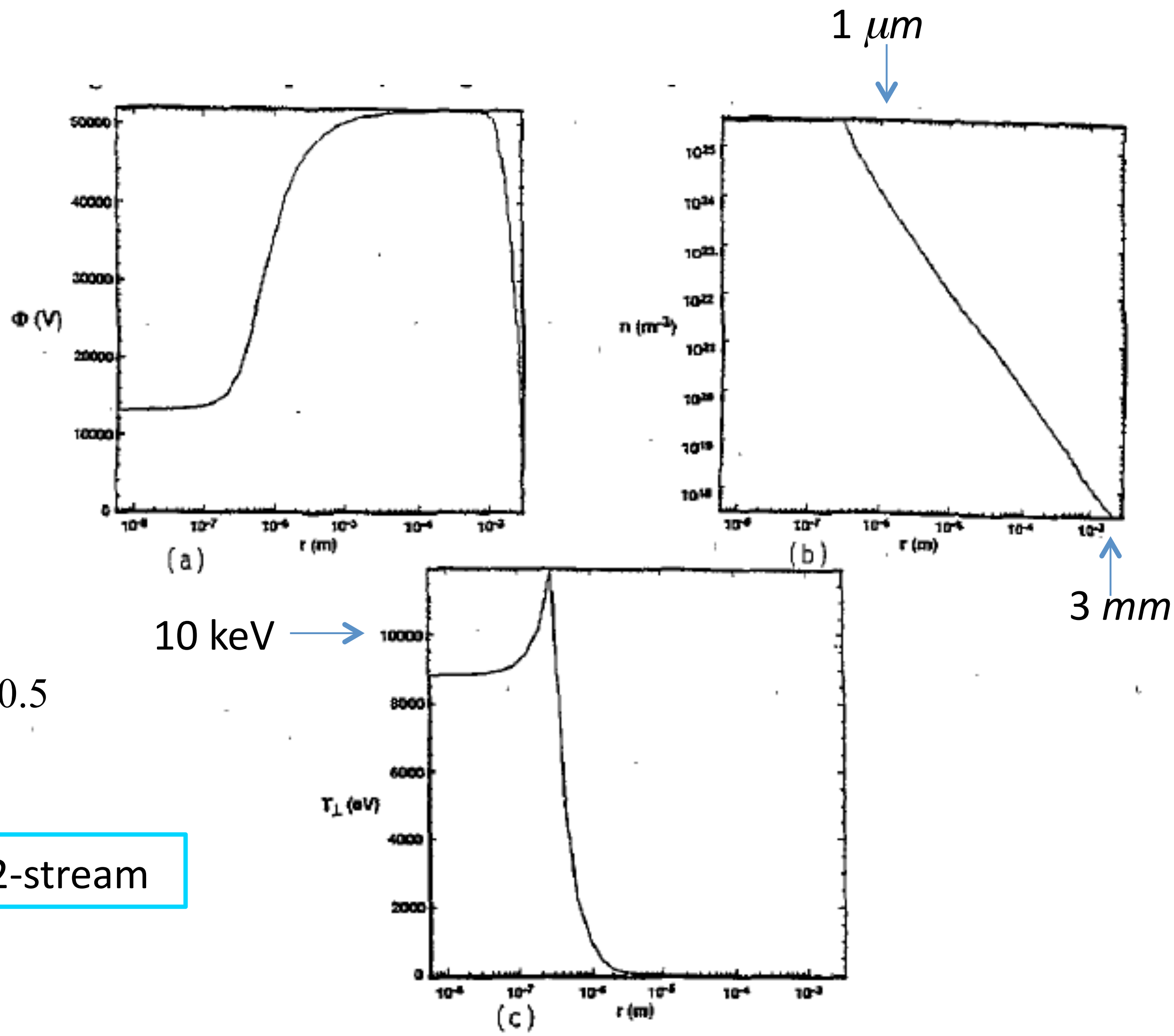
PFX observations

- 30 times Brillouin
- 100:1 radial convergence
- Steady, IEC like electron distribution
- No ions
  - Liquid He system
- 30 kV w/o electrons, 8 kV with
- Poor pumping (geometry closed)

Theory

- This really is a “spherical cow”
- Theory can pretty much literally simulate system
- Solve Vlasov equation for steady state
- Solve Fokker-Planck equation for collisional effects
- Calculate stability with spherical harmonics
- *Etc.*

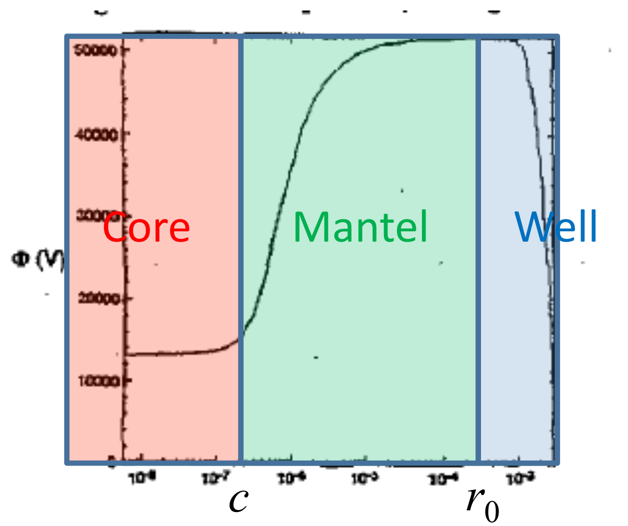
Electron-ion solution (1993)



$$f = \frac{n_{i0}}{n_{e0}} = 0.5$$

Stable to 2-stream

Scaling model



$$C = \frac{r_0}{c}$$

- Well region – neglect space charge, vacuum field
- Mantel – beam-like $\quad n = \dfrac{n_0 r_0^2 v_0}{r^2 v(r)}$
- Core – 3 x density increase, thermal, constant density, 1 Debye length

Scaling model

$$\dot{N} \approx 2\times10^{14}\,\frac{f^{2}}{\left[3\log C_{1000}+20.7+1/(1-f)\right]^{5/2}(1-f)^{1/2}}\,\frac{V_{100kV}^{4.5}C_{1000}}{a_{cm}}$$

- Very strong voltage scaling
- Linear-ish scaling with convergence
- 1/size dependence
- $f \sim 1/2$ sufficent
- Neutron rates $10^{9}-10^{10}$ may be achievable

For example

- V = 100 kV, a = 1 cm, D-T, B = 0.15 T, $\bar{n} = 2.2 \times 10^{17} m^{-3}$
  - C = 3000, $\dot{N} = 6.2 \times 10^{10} s^{-1}$
  - C = 100, $\dot{N} = 7.2 \times 10^{9} s^{-1}$
- Q ~ 5 x 10^{-3}, 5.6 W for 10^{10} neutrons/s
- V ↗ 300 kV, Q ↗ 0.5 – 1 !

Practical problems

- Arcs & sparks – lots of voltage in small system
  - Even the “air” side is challenging
  - Vacuum side requires lots of “black” art
- Quality of injected electron beam
- Need for excellent vacuum (working pressure is < order 10^{-5} Torr)
  - Electrostatic confinement is excellent
  - Charge exchange will kill T_i

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Embellishments

- Induce POPS in confined ions
  - Increase effective reactivity
  - Increase effective heating rate
- Exotic scheme to fuel central cathode
  - Supersonic gas jet + cryopump?
- Heat engine (extensions of POPS)
- …

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Future

- Currently no funding
  - “garage” scale experiment, hydrogen or deuterium?
- Technical features
  - Permanent magnets?
  - Room temperature bore
  - Use oil on “air” side
  - Make anode a mesh (probably slotted)
  - Use getters?
  - Magic cathode materials (Ti, Cr, Mo, Li?)

Summary

- PFX produced spherical focus, deep virtual cathode in miniature system
- Significant Q at mW fusion level
- Only need modest (but challenging) technology improvements to make Q ~ 1
- This speaker (and his past and present collaborators) welcomes your input

Published References

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