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Project ALPHA

Antihydrogen Laser PHysics Apparatus

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University of Manitoba: *G. Gwinner*

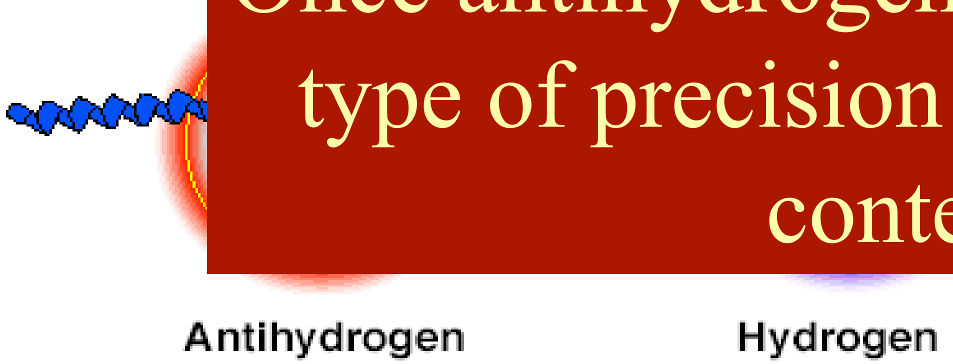
University of Calgary: *R.I. Thompson*

** current address: Laboratoire de L'Accelerateur Lineaire; Orsay*

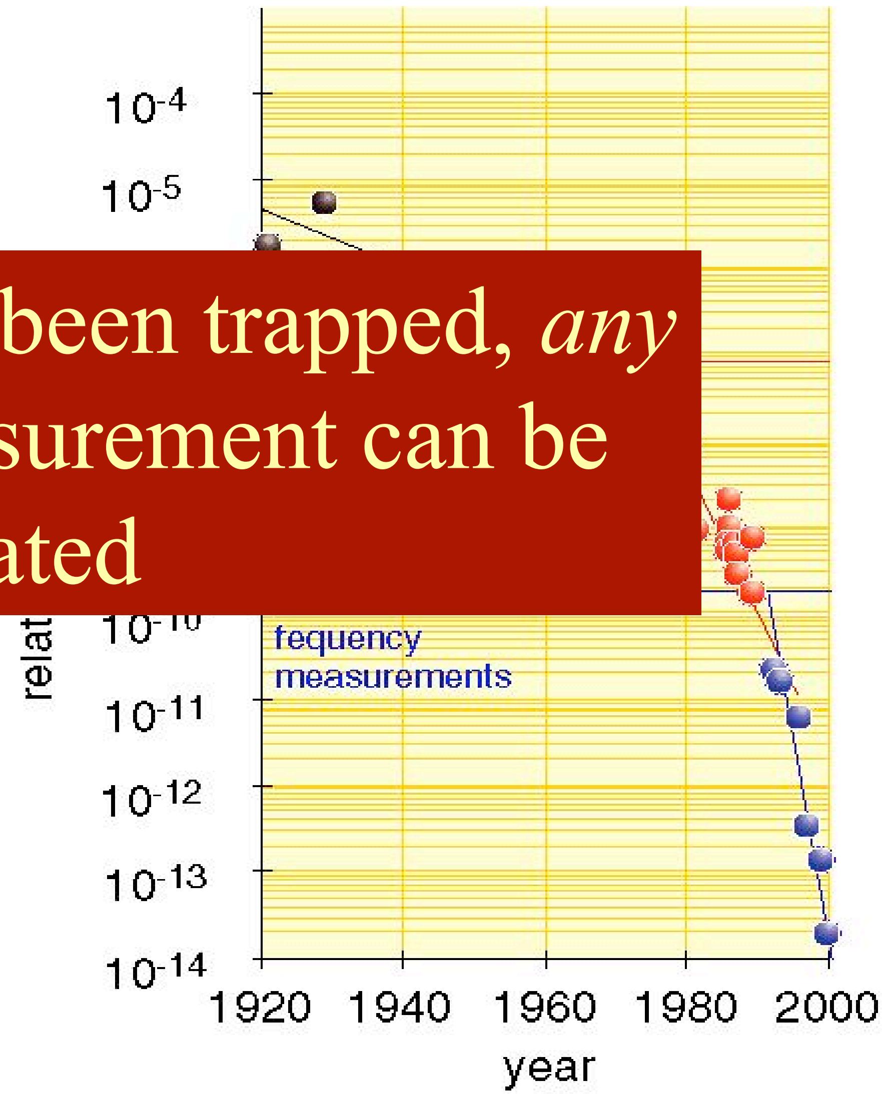
α Precision Spectroscopy - Still the Goal

1s-2s two-photon spectroscopy

Once antihydrogen has been trapped, *any* type of precision measurement can be contemplated



“Hänsch Plot”



- **Doppler effect cancels**
- **High precision in matter sector**
- **test of CPT theorem**

α Philosophy & Strategy

• The original vision of the AD program - conducting tests of CPT symmetry based on antihydrogen spectroscopy - remains our unique focus

• We believe that it is essential to trap antihydrogen atoms in order to guarantee a bright future for the field, and to be able to compete with other CPT tests

• We have begun to construct a new, purpose-built trapping apparatus that will begin work with antihydrogen in mid-2006, when the AD beam returns

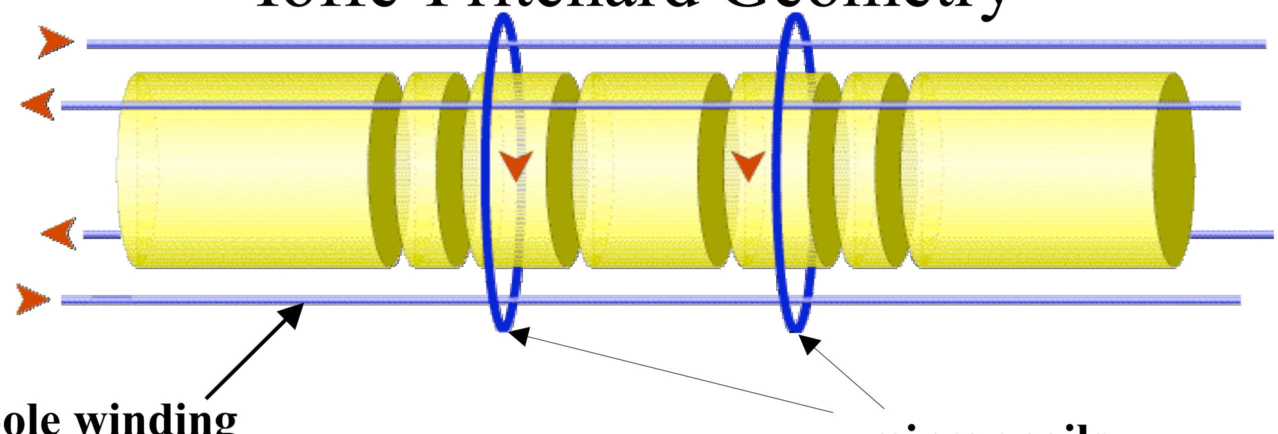
• We will concentrate on the only demonstrated method of producing cold antihydrogen: mixed plasmas of cryogenic constituents - with possible laser enhancement

•TRAPPING IS THE MAIN, INITIAL GOAL: investments and design considerations for the new apparatus will prioritize the trapping hardware

• Offline trapping studies based on variable-field, superconducting, quadrupole magnets are essential for making design decisions for the new apparatus. These have been completed.

α Trapping Neutral Anti-atoms

Ioffe-Pritchard Geometry



Aside: high n-states could have higher μ

$$\vec{B}_Q = gr\sin(2\theta)\hat{r} + gr\cos(2\theta)\hat{\theta} = gy\hat{x} + gx\hat{y}$$

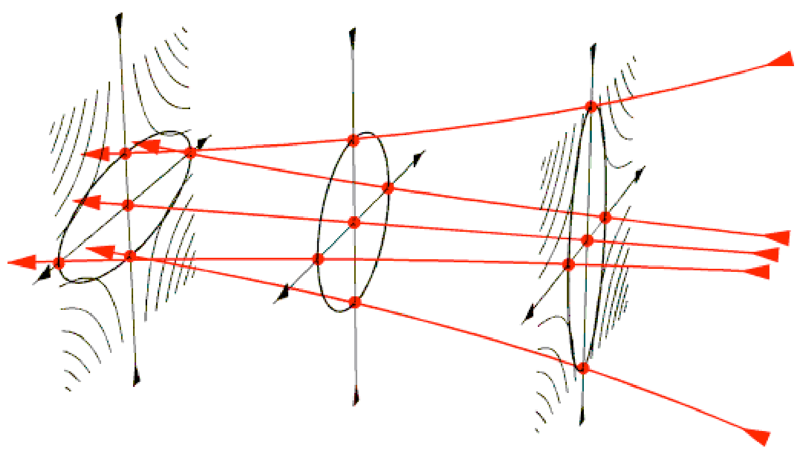
Solenoid field is the minimum in B

Based on Berkeley results: not a good idea…

α Quadrupoles - Why not?

Well depth $$\Delta B = \sqrt{B_S^2 + B_W^2} - B_S$$

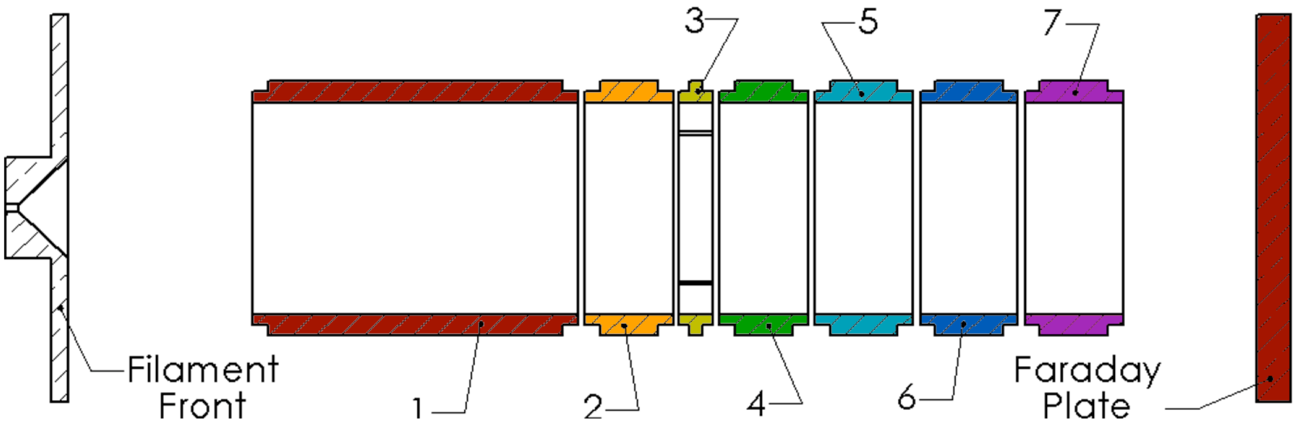
- **For STRONG fields: $B_W/B_S \sim 1$, field lines diverge rapidly to the wall; particles making axial excursions (transfer, mixing) are easily lost**

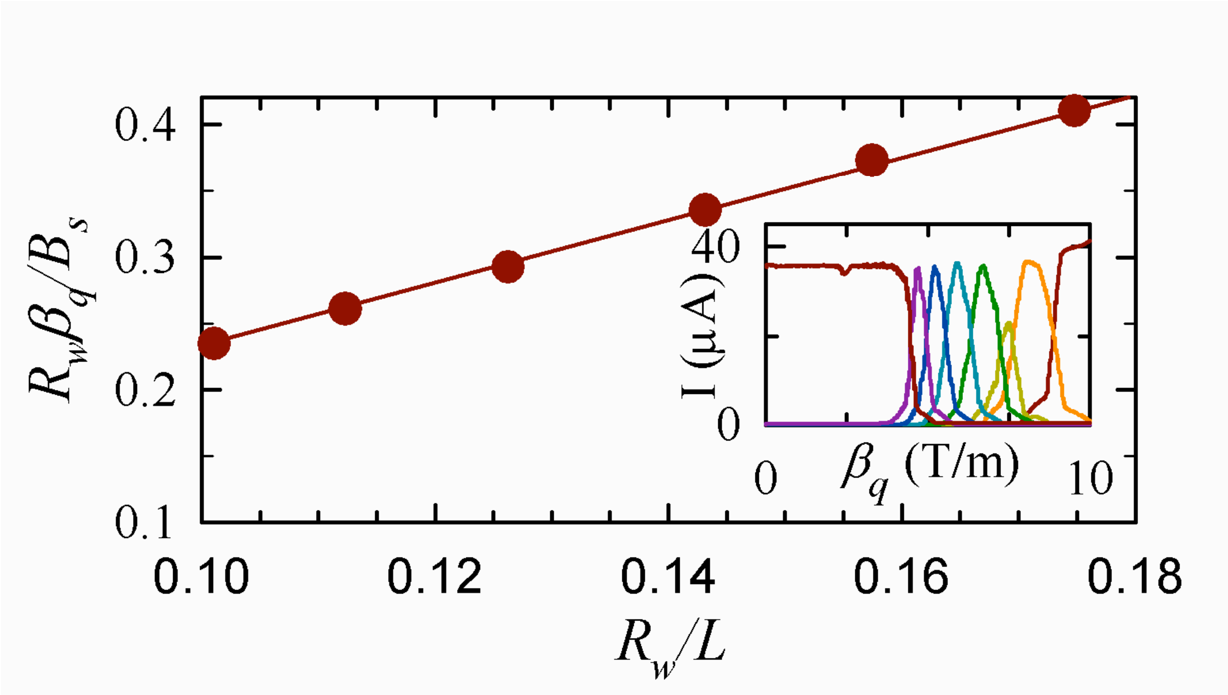


- **Quadrupole field induces diffusion that leads to loss in strong fields, even without longer axial excursions**

α Berkeley Results with Quadrupole: Loading

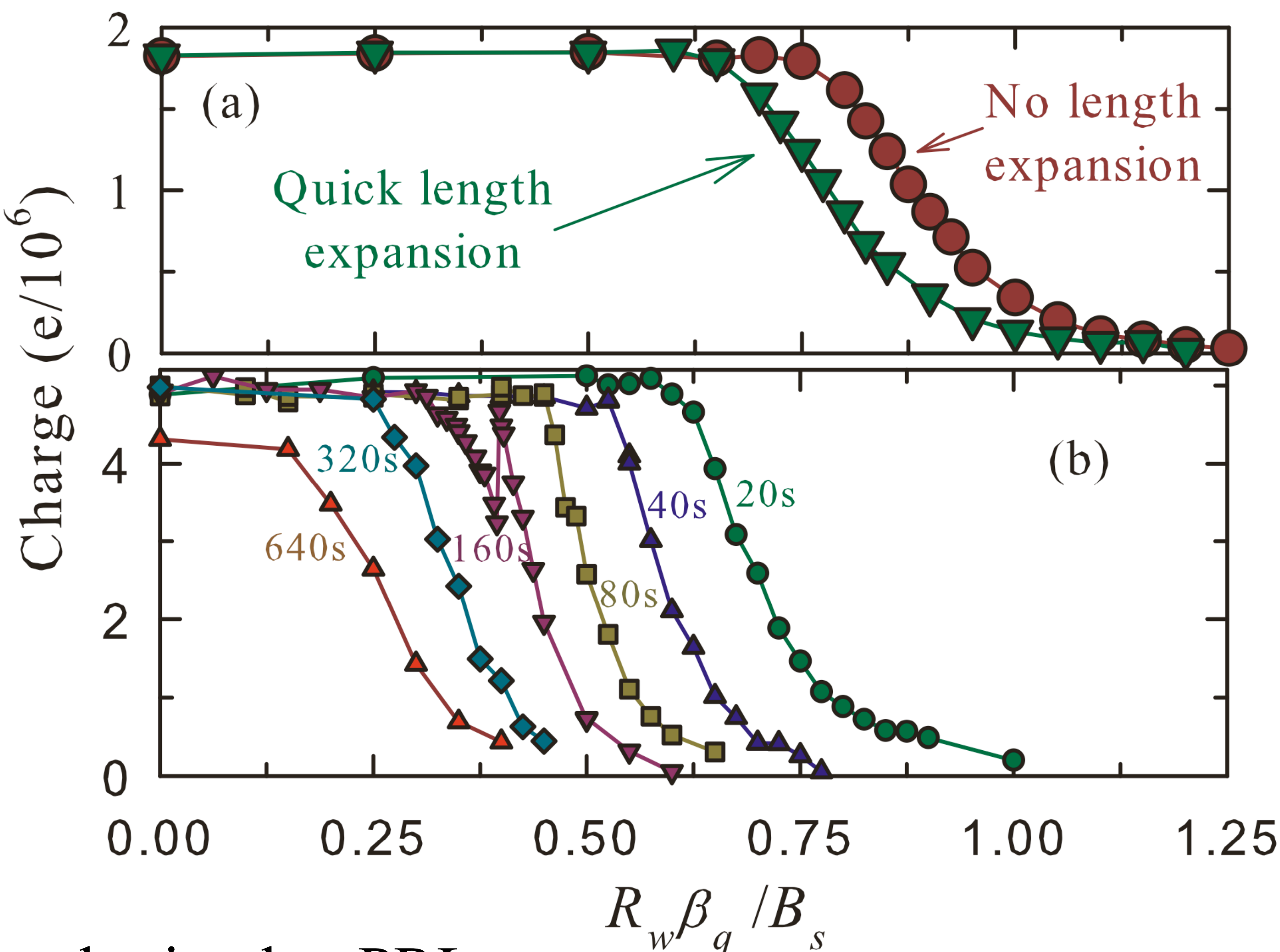
- 1 cm trap radius
- Variable quadrupole gradient β_q (T/m) up to 50 T/m
- Electron plasmas
- Solenoid up to 8 T





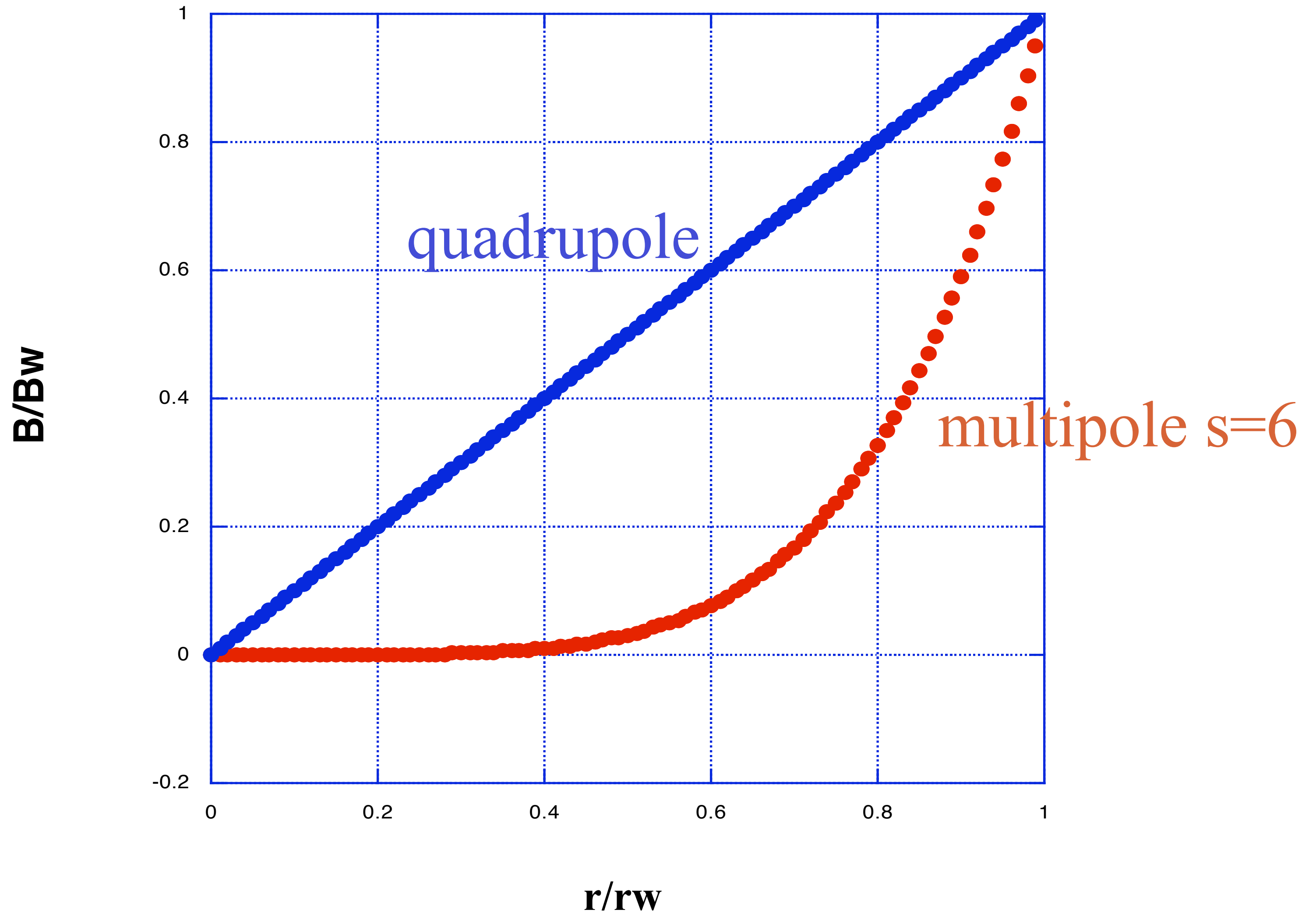
Berkeley Results with Quadrupole

1) Load electrons
2) Ramp quadrupole
3) Expand trap

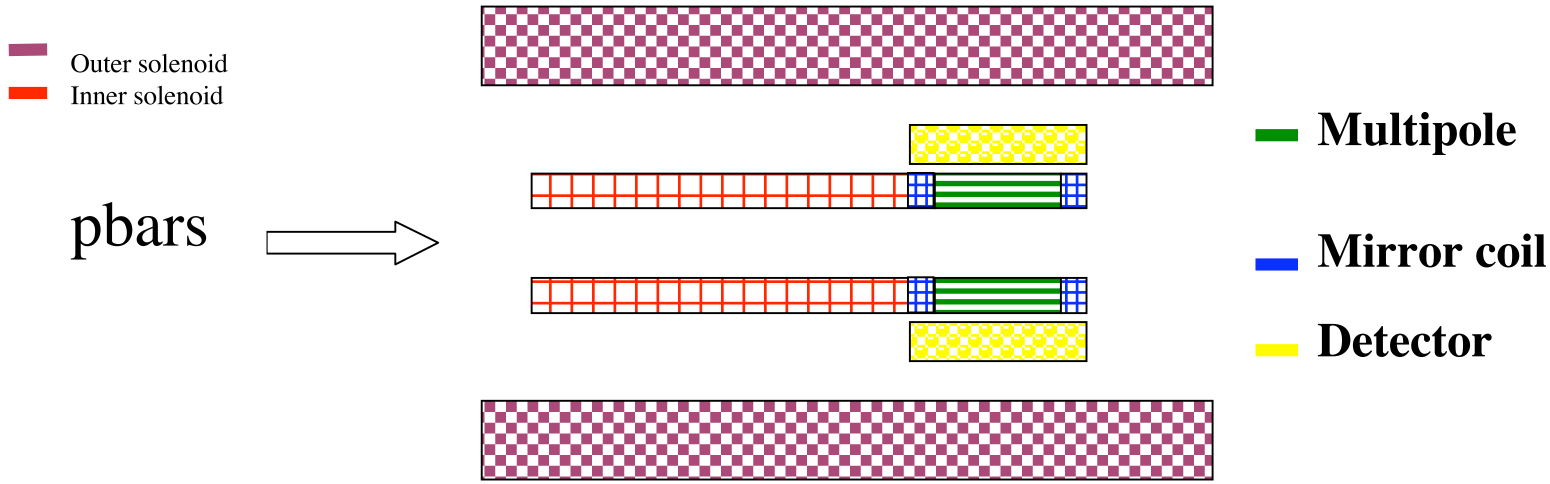


J. Fajans *et al.*, submitted to PRL

α Solution: multipole field

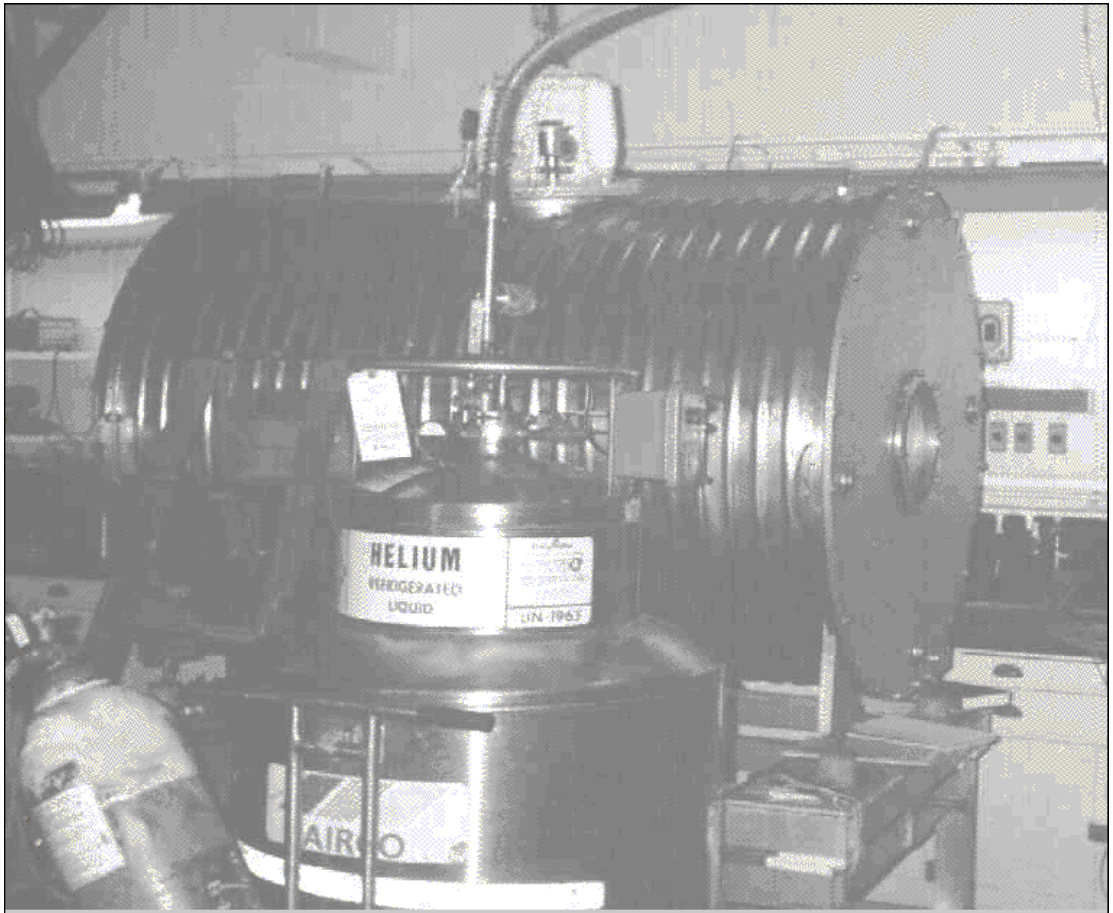


Field Configuration



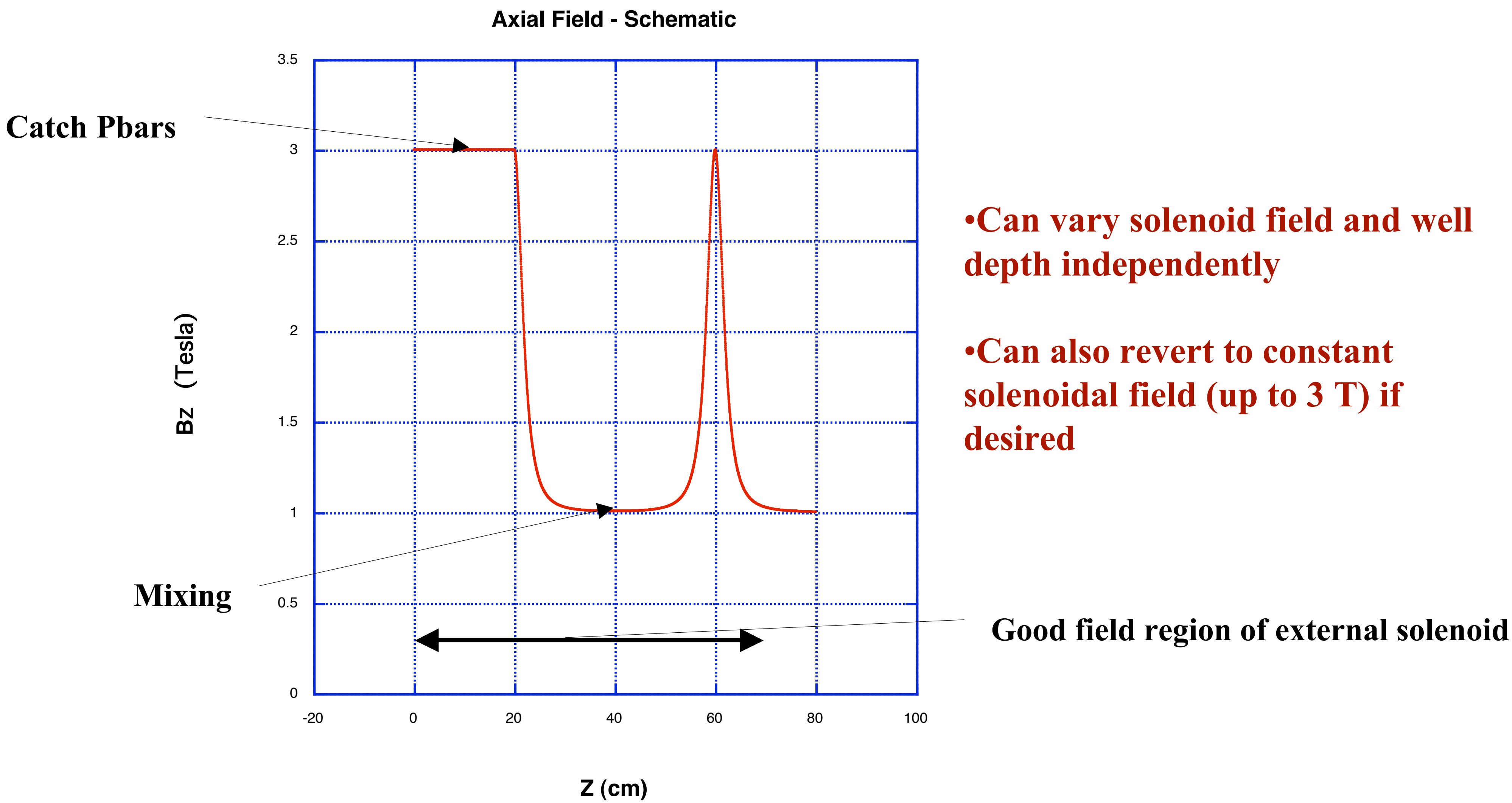
Kurchatov-Berkeley Magnet

• 3 T, warm bore 26 cm diameter
• homogeneous region (10^{-3})
100mm diameter, 700 mm long



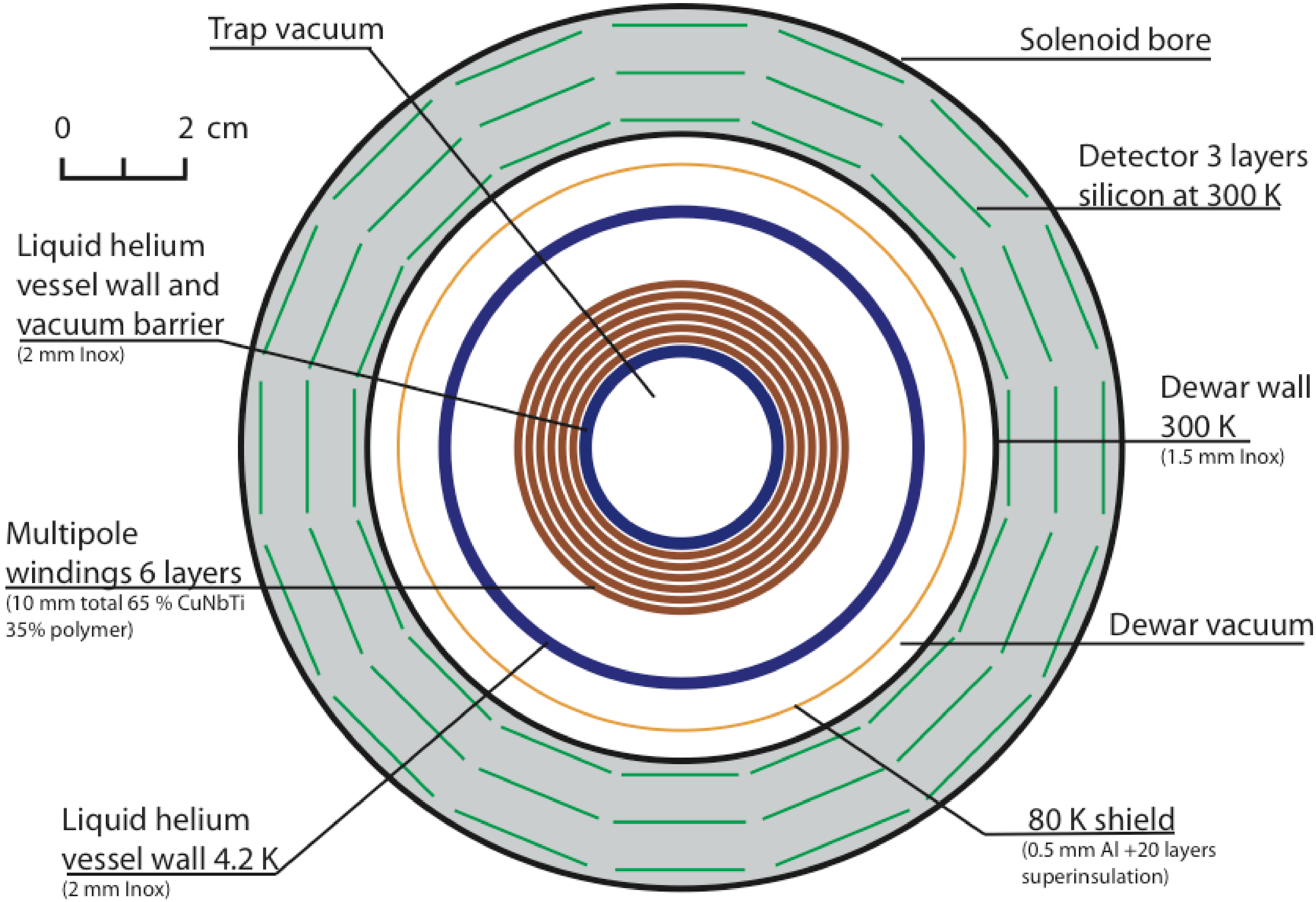
CRYOSTAT.JPG

Example Field Configuration



- Can vary solenoid field and well depth independently
- Can also revert to constant solenoidal field (up to 3 T) if desired

Schematic Cross Section



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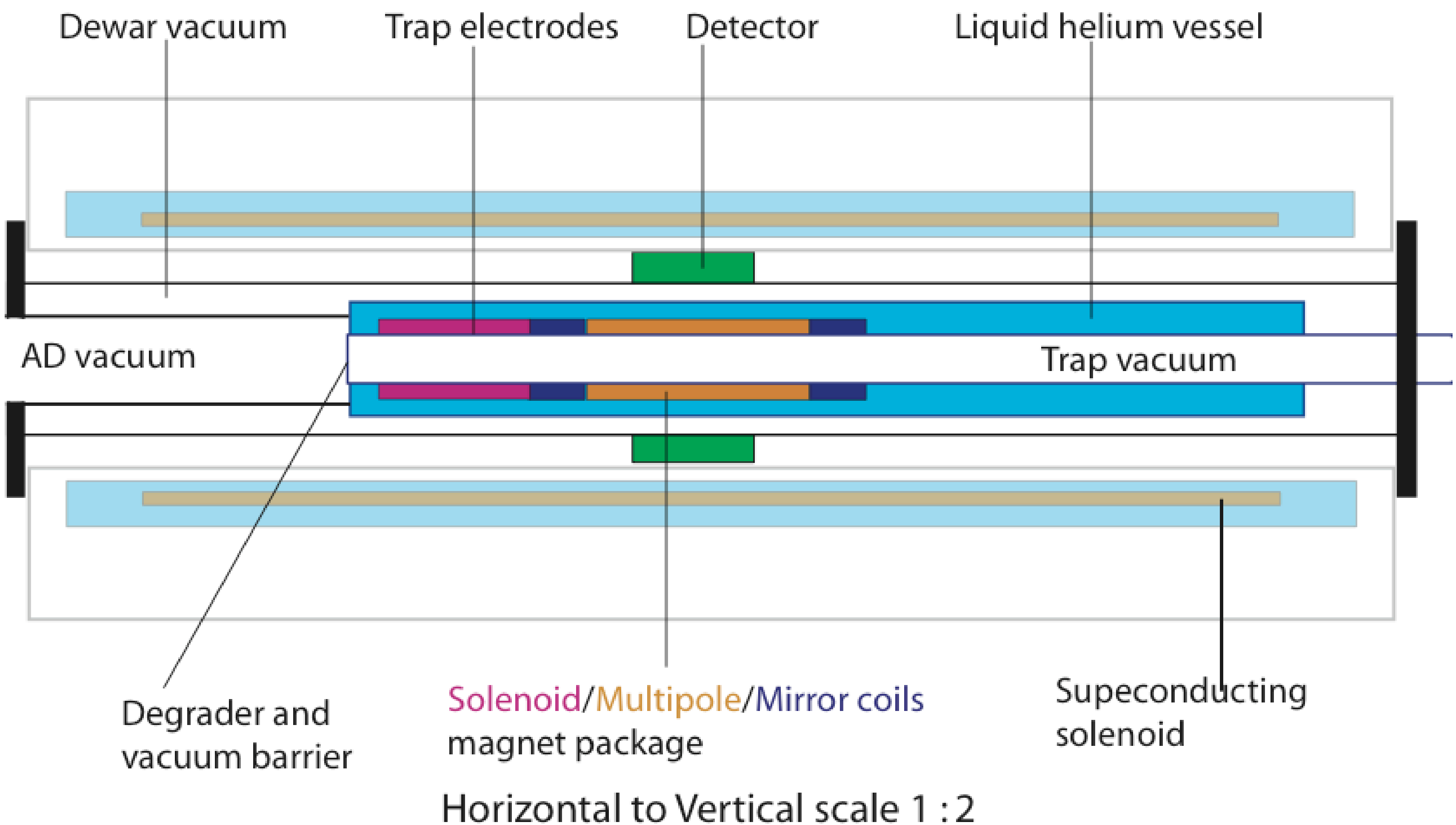
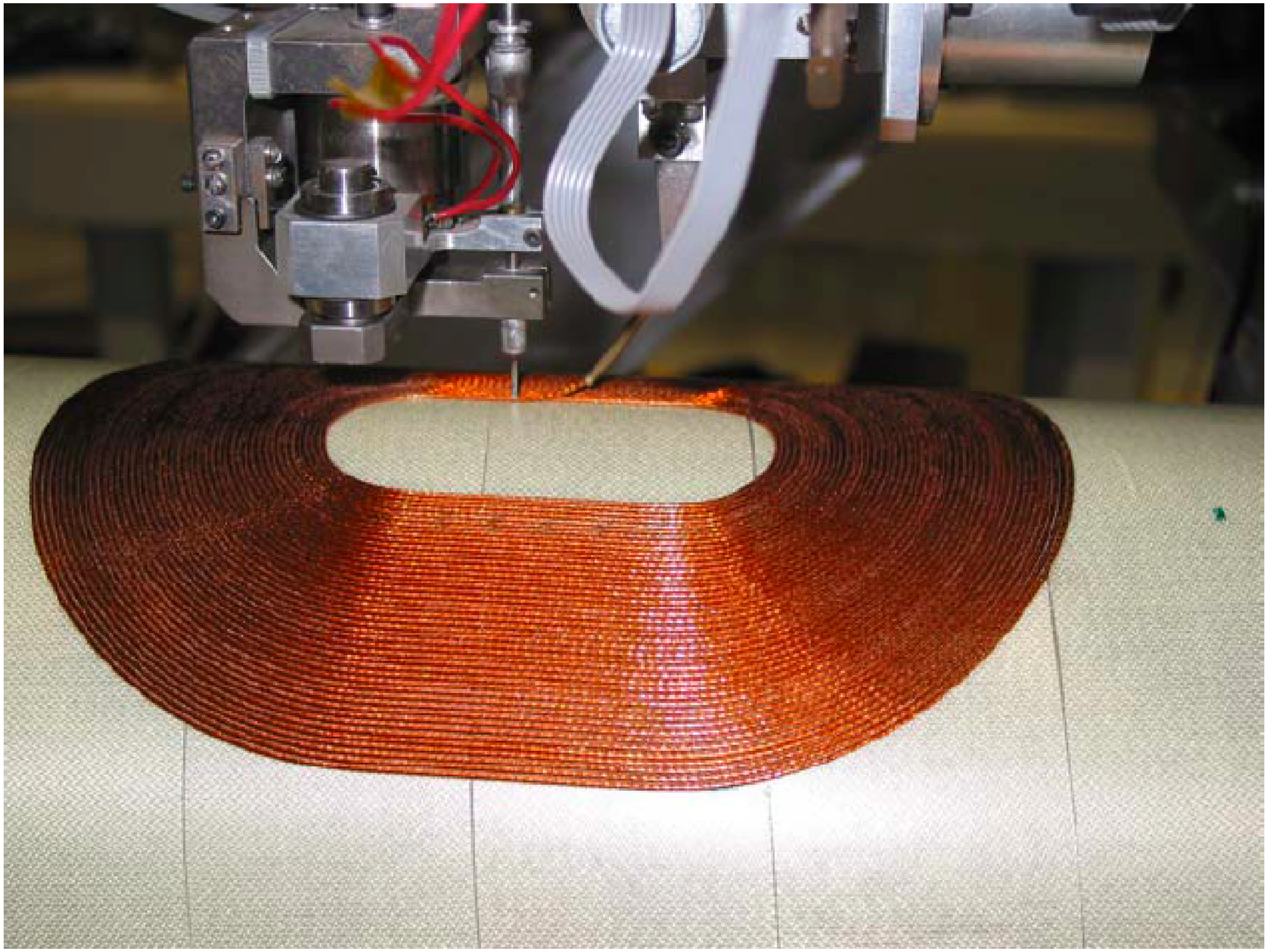


Dewar vacuum
Trap electrodes
Detector
Liquid helium vessel
AD vacuum
Trap vacuum
Degrader and vacuum barrier
Solenoid/Multipole/Mirror coils magnet package
Supeconducting solenoid
Horizontal to Vertical scale 1 : 2

BNL Superconducting Magnets



- Wind on thin, small diameter tube
- Place current as close to trap wall as possible: thin Penning trap construction necessary
- Minimum thickness for multiple scattering of pions
- High precision alignment of conductors, layer by layer correction
- Epoxy matrix - no dense metal support structure
- Combine multipole, mirror coils, solenoid, in one unit

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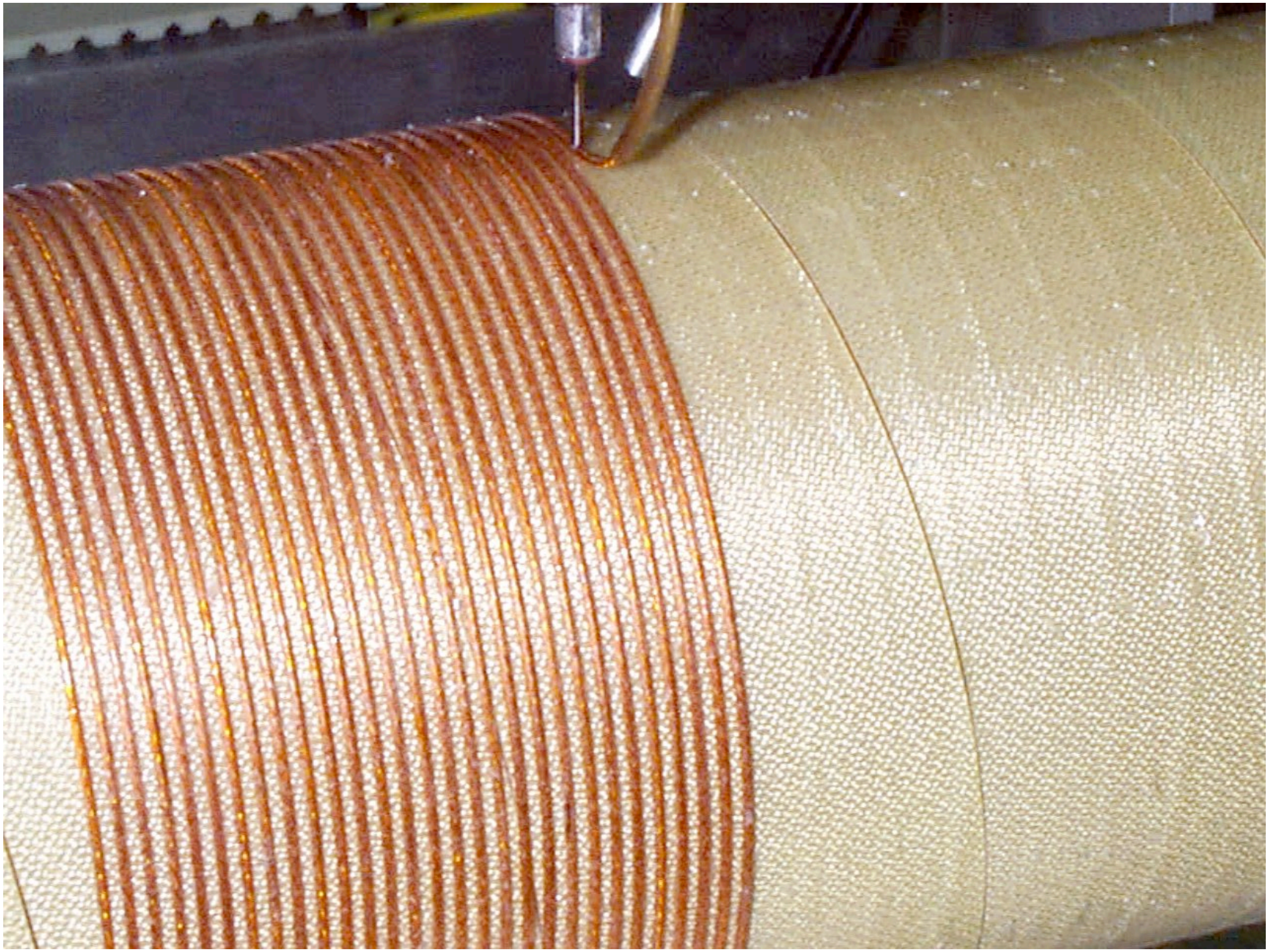
BNL Solenoid Winding



α Detection

•Need to confirm and optimize Hbar production w/o trapping fields: reproduce ATHENA or ATRAP operation

•Need to confirm and optimize Hbar production w/ trapping fields

•Need to verify trapping: probably by fast release of trapping fields

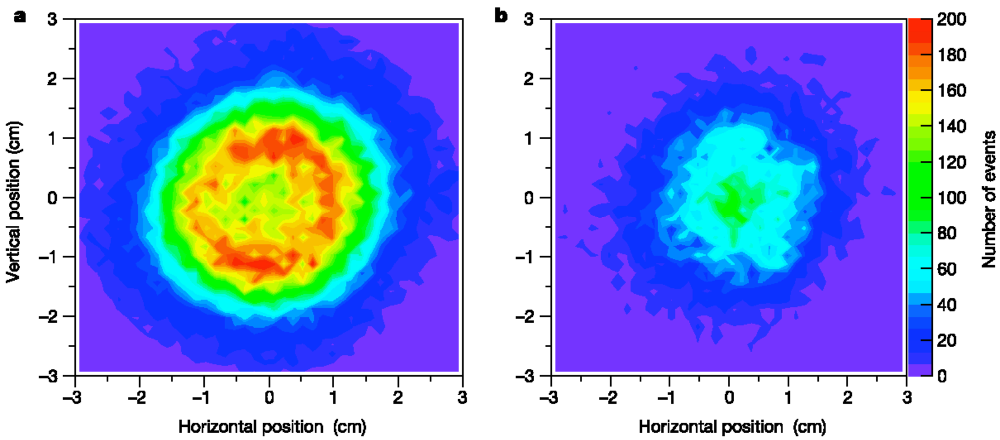
Solution:

- •Si Vertex detector - room temperature
- •External scintillators
- •Field ionization technique (ATRAP)

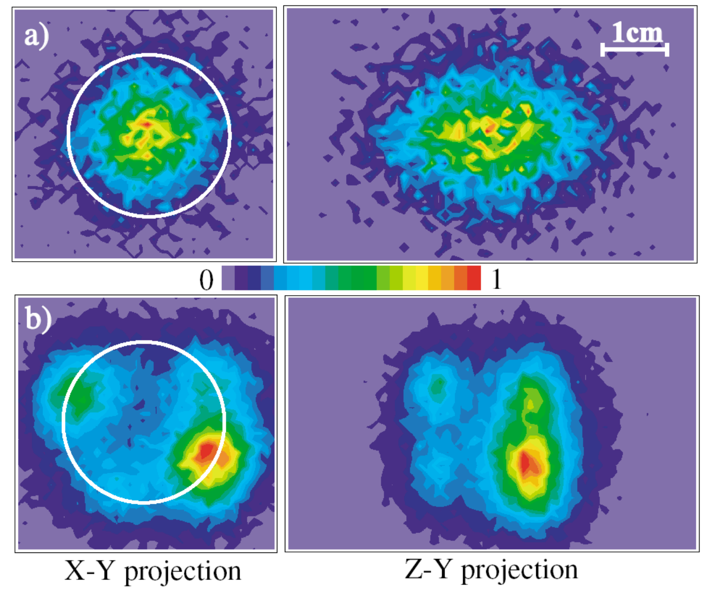
(Multipole materials preclude 511 gamma detection)

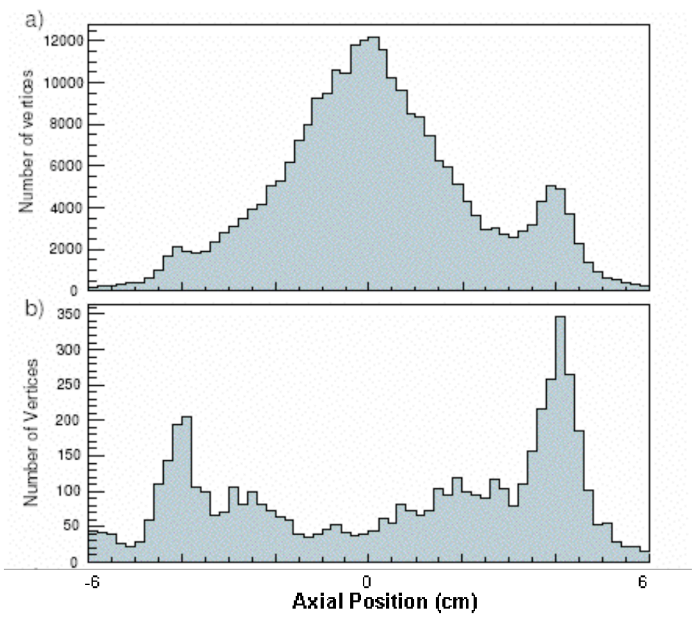
ATHENA EXPERIENCE

M. Amoretti *et al.*, Nature **419** (2002) 456.



M. C. Fujiwara *et al.*, Phys. Rev. Lett. **92**, 065005 (2004)

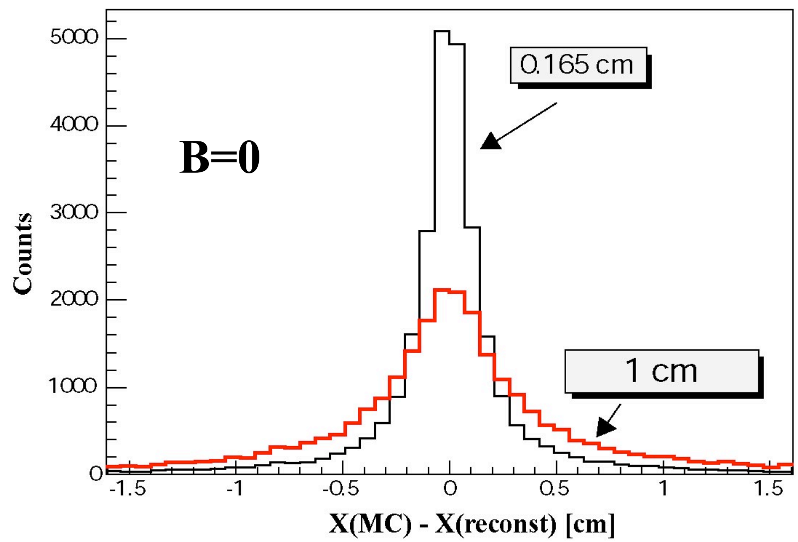


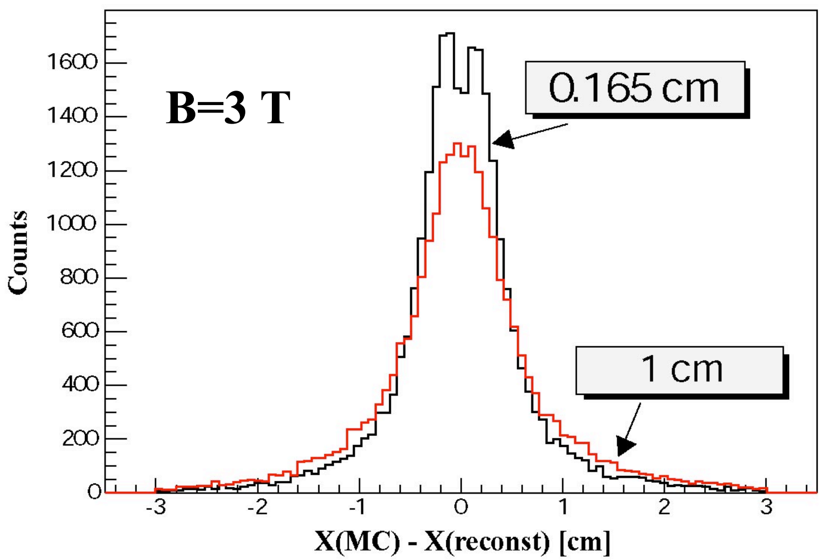


N. Madsen *et al.* to be published in Phys. Rev. Lett. (2005)

- **Can distinguish charged particle (pbar) loss from Hbar *without* 511 keV gamma detection**
- **ATHENA vertex resolution ~ 4mm (dominated by straight line fit to curved trajectory)**
- **Is multiple scattering tolerable with the multipole?**

MC Simulations*





"ALPHA"

"ATHENA"

Uncorrected curvature dominates resolution

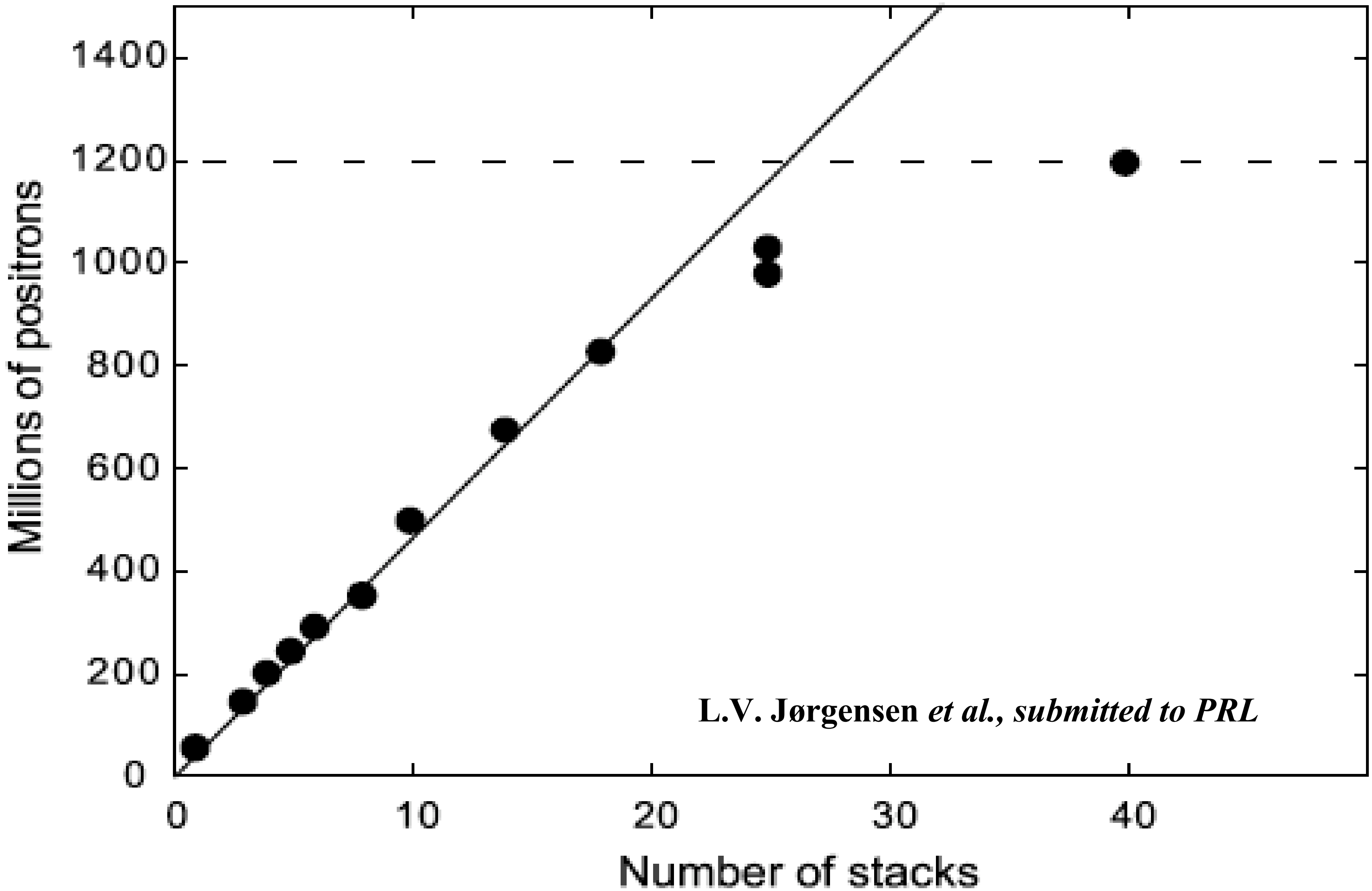
Could in principle correct for curvature with 3-layers Si, but not obviously necessary

An ATHENA-like detector would be adequate; studying improvements

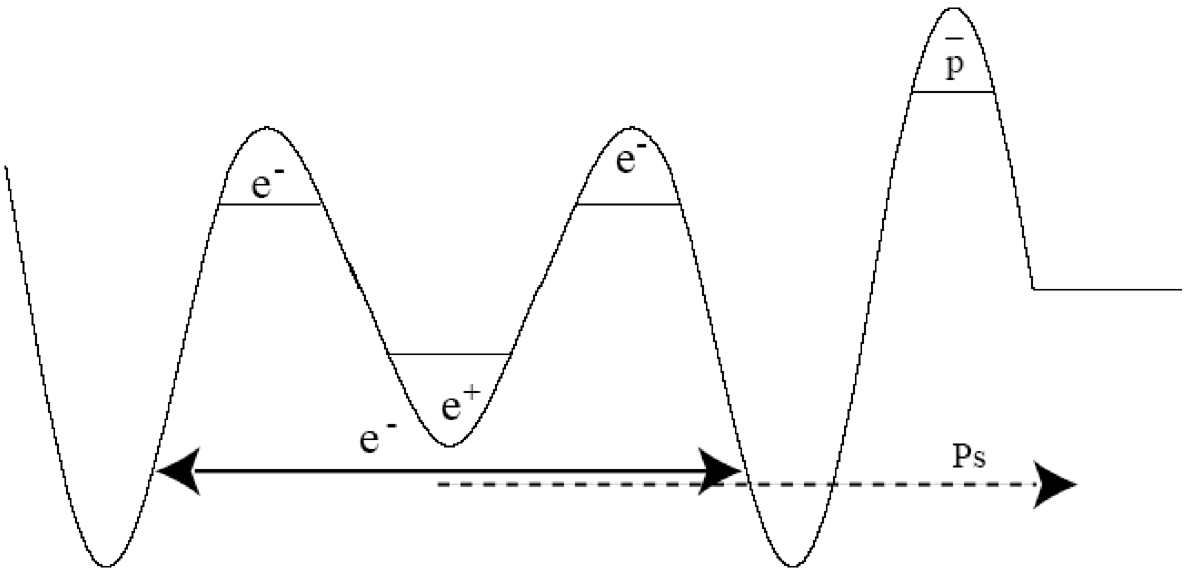
Effect of multipole field under study

*thanks to Professor A. Rotondi

Positron Improvements



α Hbar by Positronium Production ?



α Other Systems - In Brief

- **External detection: scintillators with PMT's or HPD's - patterned after ATHENA**

- **Trap control and sequencing: new system based on National Instruments FPGA, Berkeley design; Labview interface**

- **Beam position monitor: segmented silicon**

- **Monte Carlo: GEANT4 under development; ATHENA MC very helpful - thanks again Alberto**

- **Lasers: all ATHENA systems retained (1s-2s; CO_2), Rio hydrogen lab with trapping, Calgary, Manitoba add new capabilities - pulsed lasers**

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The Immediate Future

- January 31/February 1 - meeting at BNL to work out details of coil package, cryostat
- February 15th - Liverpool detector technical proposal and schedule
- Trap fabrication trials and tests with electrons - Aarhus and Berkeley
- Monte Carlo development - 3rd layer of Si?
- Wire chamber feasibility
- Sequencer development

α Collaboration Strengths

ATHENA/ASACUSA experience: Aarhus, Riken, Rio, Swansea Tokyo - technical and physics coordination, all aspects of ATHENA construction and operation

The world's best source of slow positrons: about to get even better

Non-neutral plasma physics: Berkeley (experimental); Auburn (theoretical) - key ideas, experiments and models, diagnostics, control

Silicon detectors: Liverpool - a comprehensive facility with large-scale production capability - also external detectors and gamma detectors, DAQ

Lasers: Aarhus, Calgary,Riken, Rio, Manitoba, Swansea, Tokyo - 1s-2s; high power CO_2, Pulsed lasers, stimulated recombination, ionization, de-excitation, etc.

THE ONLY THING LACKING IS ELENA

Costs

Running costs (Common fund)

Operator	65 kCHF
Electronics pool	35 kCHF
Cryogens	10 kCHF
Maintenance	7 kCHF
Computers	4 kCHF
Printing	1 kCHF
Fax & Telephones	2 kCHF
Consumables	2 kCHF
Total	126 kCHF/year
	6.3 kCHF/physicist/year

Replacement investments

Cryogen handling	25 kCHF
Scintillators+PMT's	50 kCHF
Trap potential control	15 kCHF
Computer cards	12 kCHF
Trap high voltage	10 kCHF
Data logging equipment	5 kCHF
Mode diagnostics	10 kCHF
Electron gun	5 kCHF
HPD's + scintillators	15 kCHF
Total	147 kCHF

Detector

Silicon	150 kCHF
ADC	100 kCHF
Mechanical support	50 kCHF
Repeater card	20 kCHF
Power supplies	10 kCHF
Technician (2 years)	120 kCHF
Total	450 kCHF

Multipole magnet

Winding	140 kCHF
Power supply	100 kCHF
Cryostat	100 kCHF
Helium system	20 kCHF
New traps & cabling	20 kCHF
Total	380 kCHF

Total investment cost	977 kCHF
Total running cost	630 kCHF
Grand total	1.6 MCHF
	320 kCHF/year
	16 kCHF/physicist/year