H^- Field Stripping Measurements

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H- Transport and Injection Mini-Workshop

Fermilab

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Field dissociation rates

- **At dawn of quantum mechanics 1928 Oppenheimer (Los Alamos director) calculated the rate of field dissociation of H atom by essentially the Born approximation. At 1 V/cm the atom had a lifetime of $10^{10^{10}}$ seconds.**
- **Fowler-Nordheim formula for electron tunneling lifetime through a 1/r potential with added field E**

$$\tau = \nu^{-1} \exp\left(\frac{4}{3}\sqrt{\frac{2\boldsymbol{m}}{\eta^2}}\frac{\boldsymbol{I}^{3/2}}{\boldsymbol{eE}}\right)$$

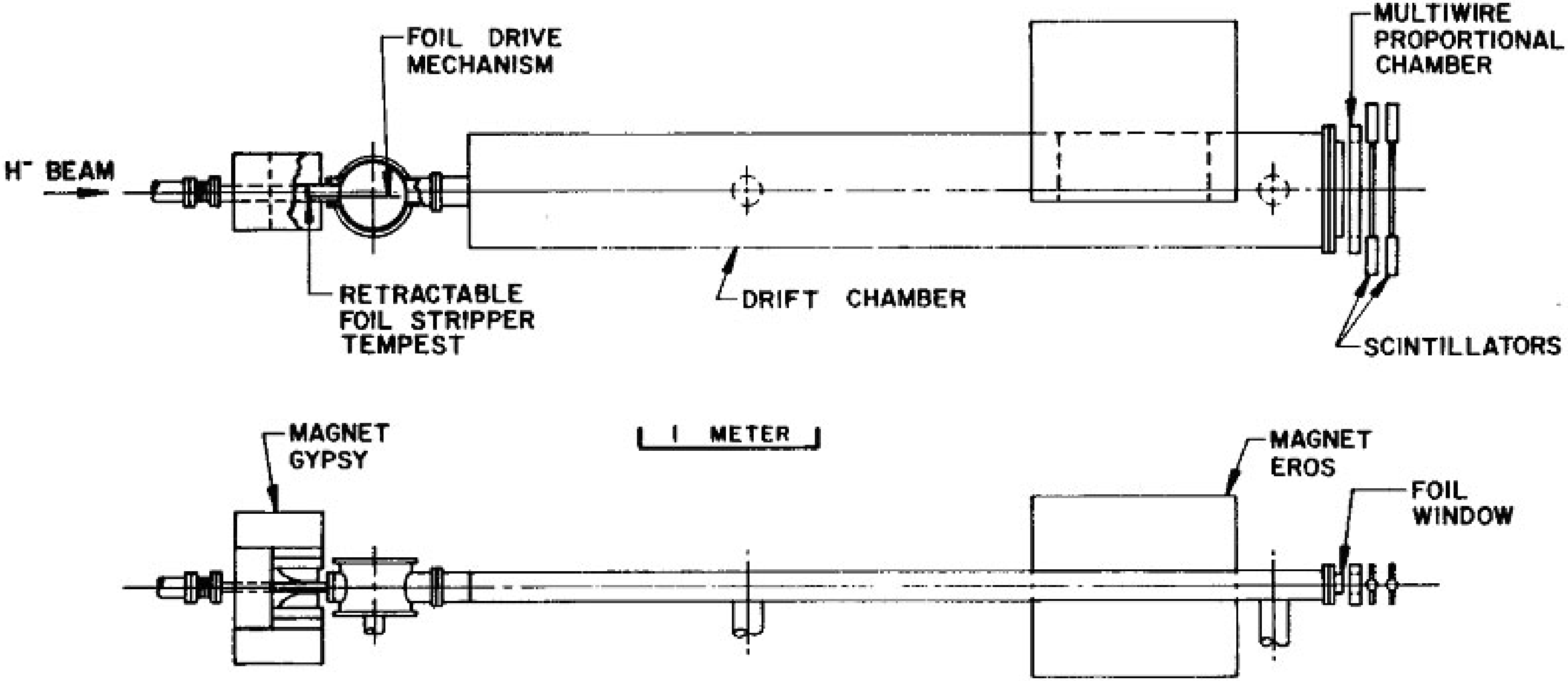
where ν is a barrier arrival frequency (atomic vibration frequency) and I is the ionization potential. Direct application of WKB approximation.

  - **For H- with electron affinity of 0.754 eV, the coefficient of 1/E is 4.47×10^9 V/m (compares with experiment value of 4.49(±0.01) $\times10^9$ V/m)**
  - **Good agreement due to large orbit of extra electron that sees 1/r potential**

- **Leonard Scherk (1979) determined the pre-exponential by more rigorous methods that included the neutral core. Result was expressed as**

$$\tau = \frac{A_1}{E}\exp\left(\frac{A_2}{E}\right)$$

Apparatus used in Exp 530 in 1980

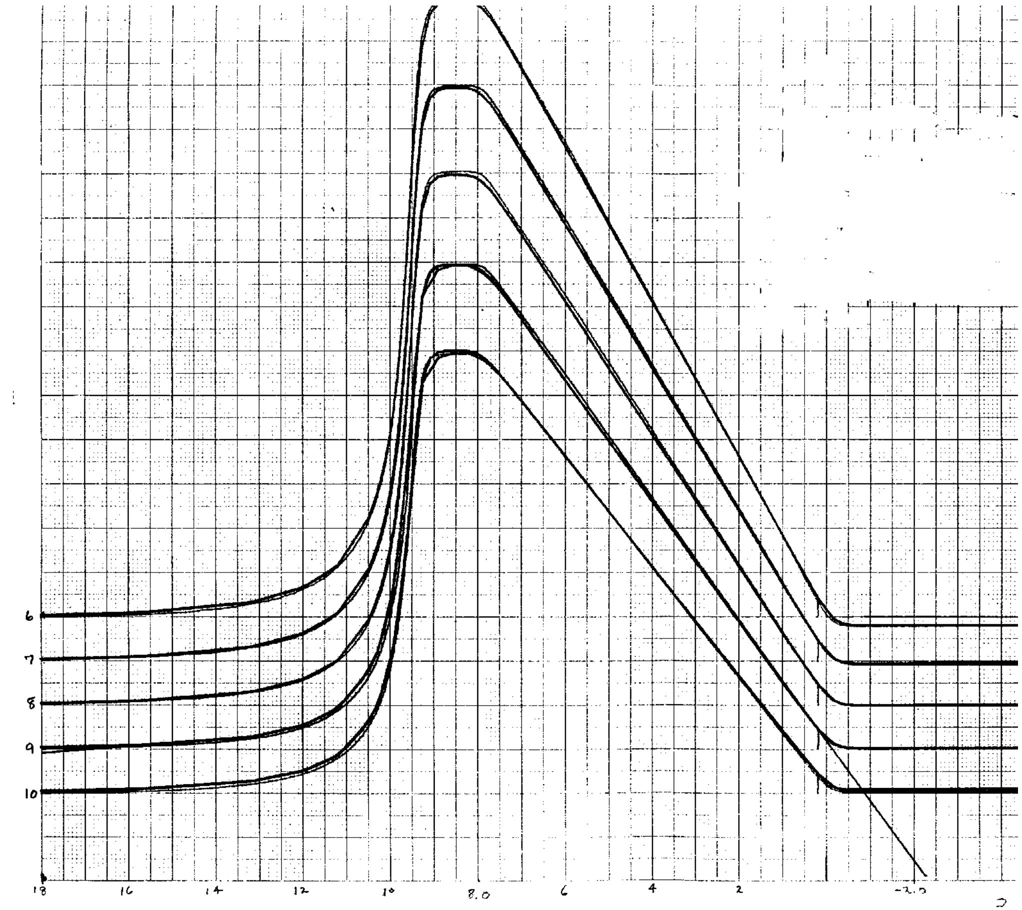


Apparatus allowed several modes

- Line EPB at LAMPF (797 MeV) used that had capability for beam attenuation to countable levels. Collimator was imaged on detector to give 1.5 mm diam hard edged spot.
- Beam went through "Gypsy" a magnet built for the experiment as the field stripper that produced a vertical field. $E=\gamma\beta cB$
- A movable thin formvar foil ("Tempest" 60 $\mu g/cm^2$) in the chamber allowed coordination of stripping point with field map. H^+, H^-, and H^0 were seen originating at the stripping point. Results agreed with trajectory calculations
- A long vacuum chamber (5.4 m) allowed separation of the neutral and charged beams
- Magnet Eros (further) separated particles of differing charge
- Beam then passed through multiwire proportional counter and scintillator pair that acted as event trigger and aided in pulse height analysis. With discrimination $S/N>10^5$

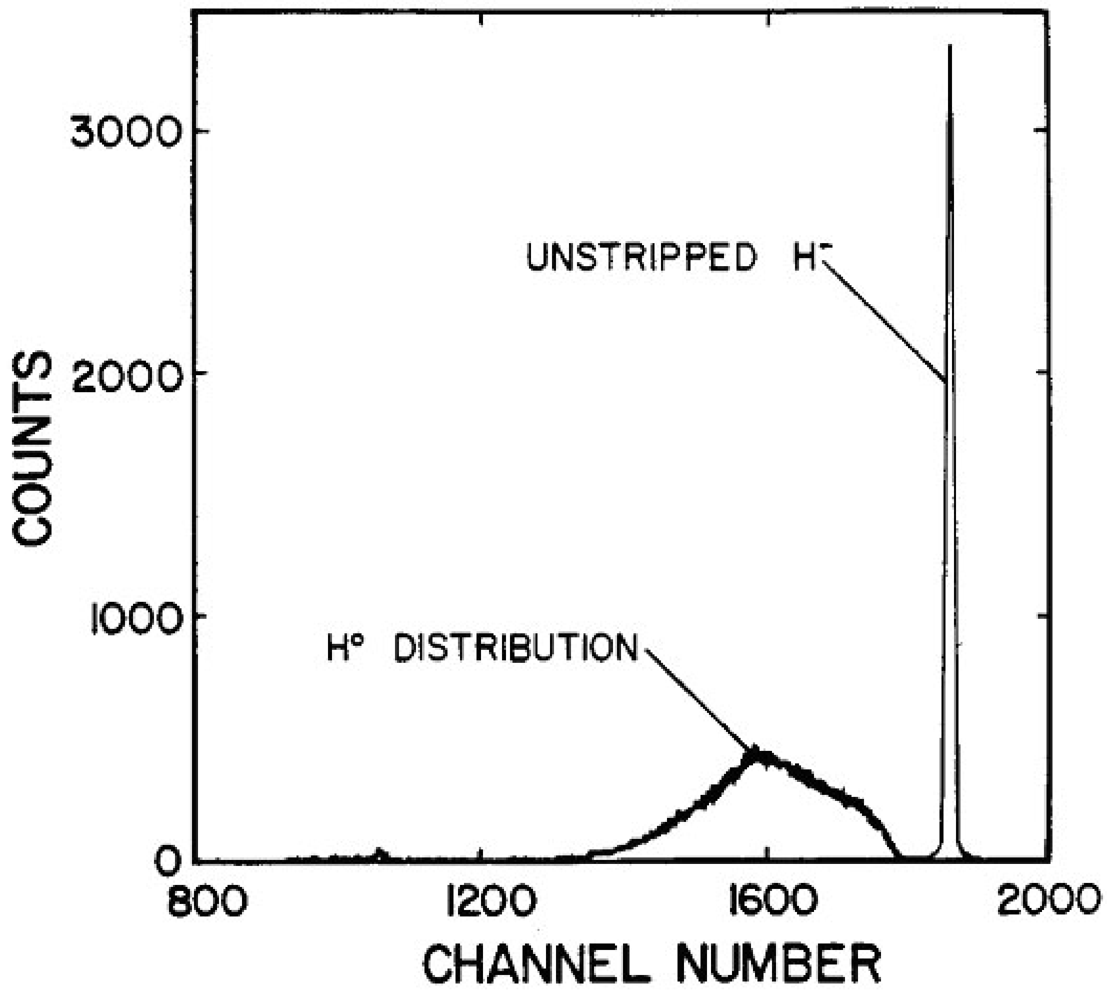
Magnet Gypsy description

- **In the normal position, beam passed through zero-field magnet yoke**
- **Then through a linear field region created by hyperbolic pole pieces**
- **Then through a flat-pole piece region where the field was highest**
- **The magnet was reversed during the experiment to obtain high field rates.**

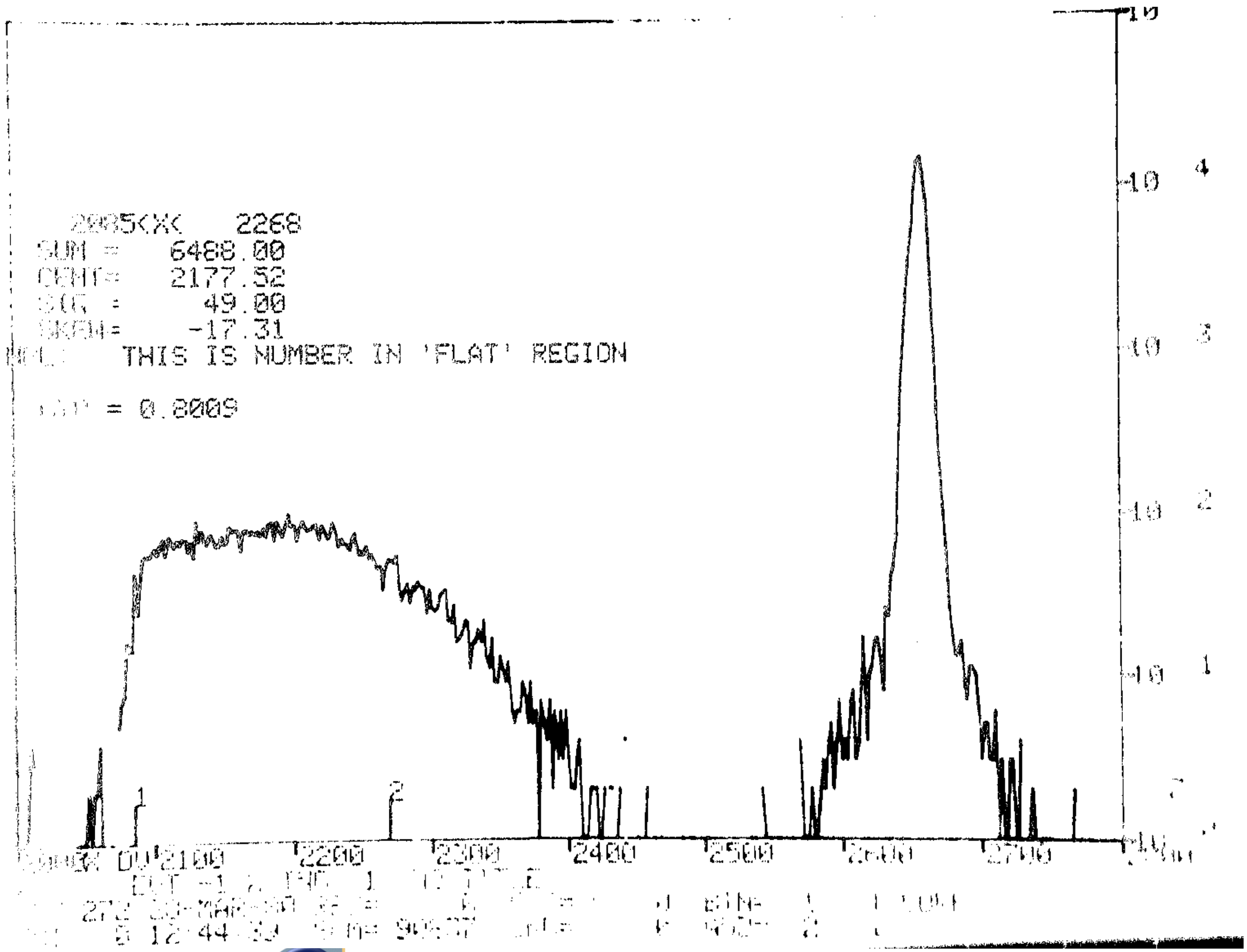


X-Y recording of Gypsy map at various currents

Data in Gypsy normal orientation, peak field of 1 T



Log plot with Gypsy in reverse orientation



Data analysis was simple (in principle)

- Counts on a particular wire

$$\Delta N(s) = \frac{N(s)}{\lambda(s)} \Delta s$$

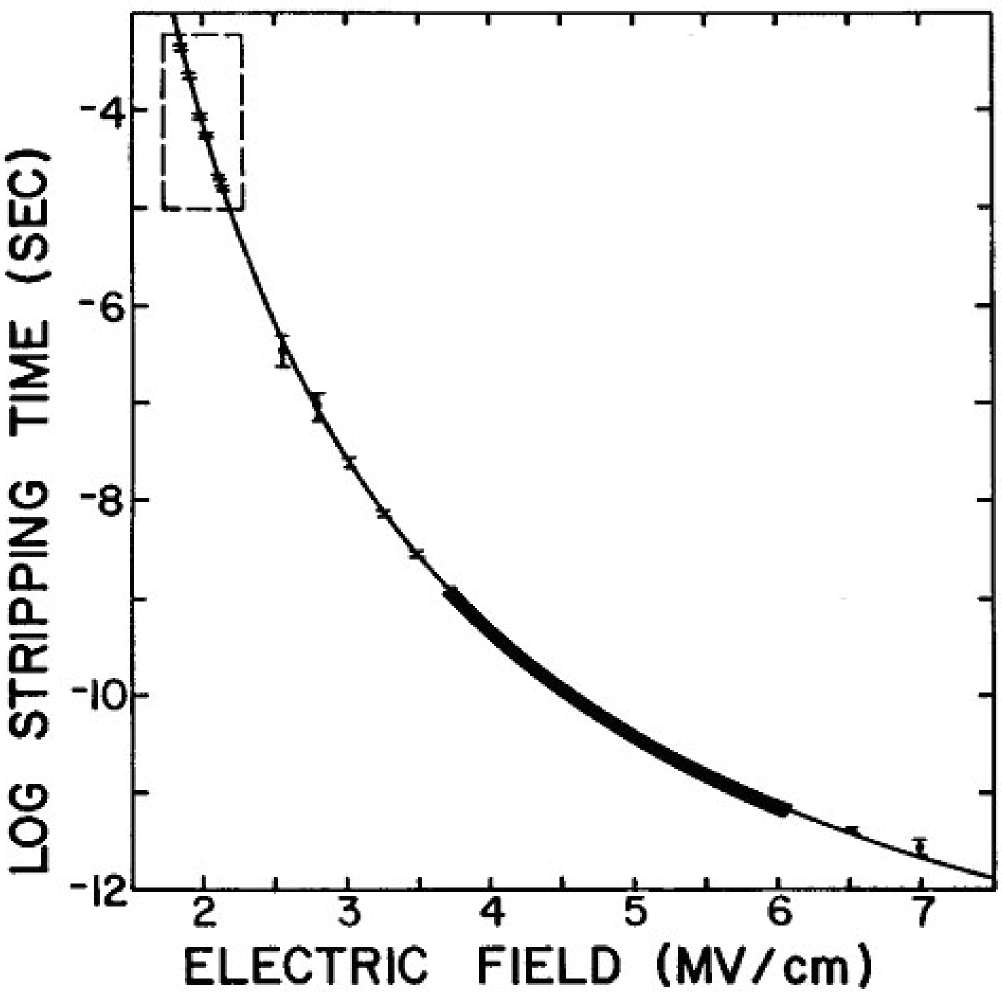
where s is the distance along the beam trajectory and λ is the stripping length at the field *B(s)*

- The stripping length is related to the lifetime by

$$\lambda = \gamma\beta c\tau$$

- High field measurements were made with the magnet reversed, at the flat poles, since in the long interval along the linear field rise, few particles got to high fields. Discrete rates were also generally measured in this configuration
- With the magnet in the normal position, a continuous measurement was possible

Lifetime results shown graphically



- Results span nearly 9 orders of magnitude
- Data in box are from Stinson et al., a similar measurement at TRIUMF in 1969 but at lower energy
- Continuous measurements (thick line) match well with discrete measurements (points)
- Thin line is fit to Scherk theory

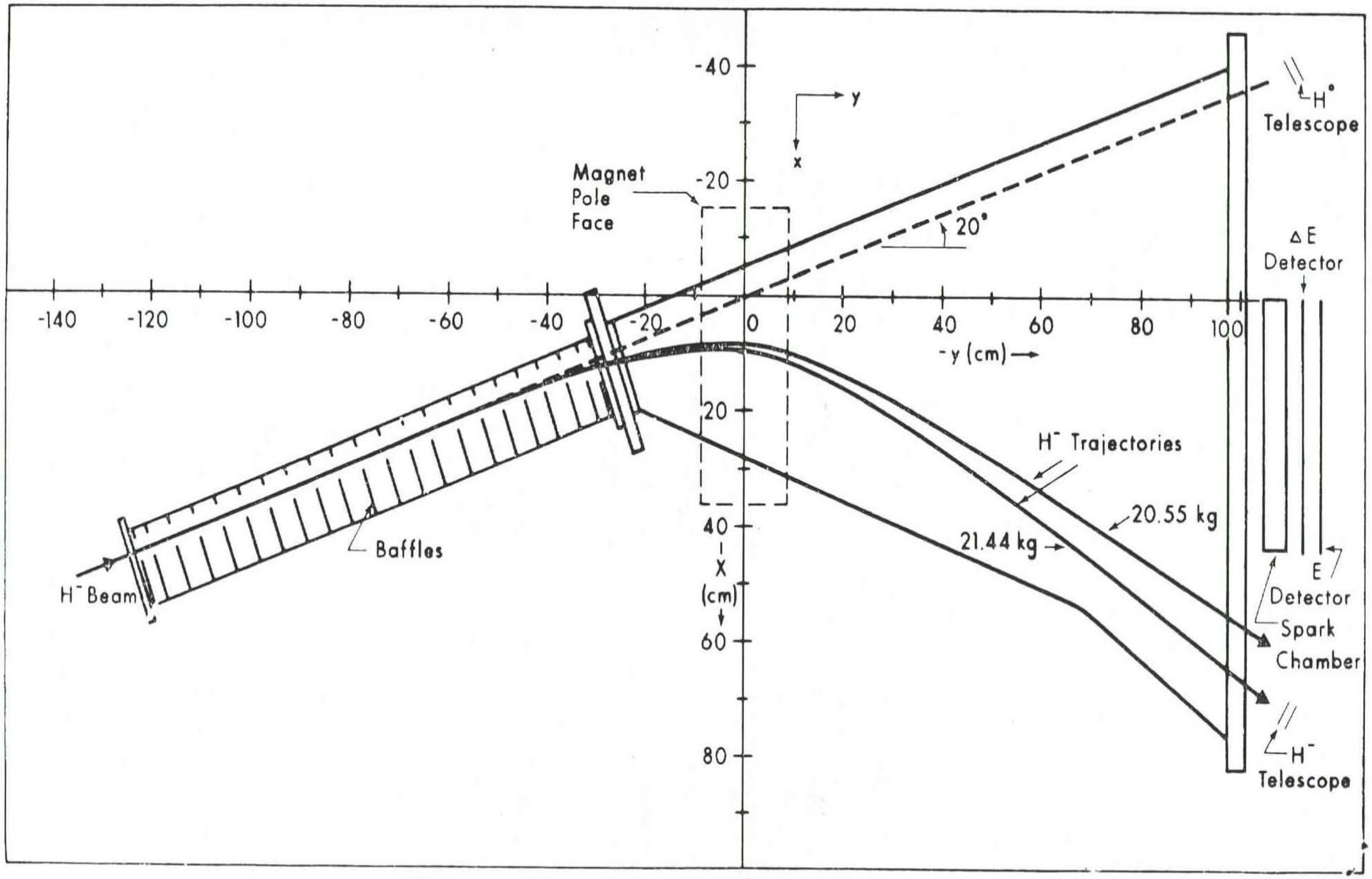
Comparison with theory

- Use Scherk result, in the beam rest frame

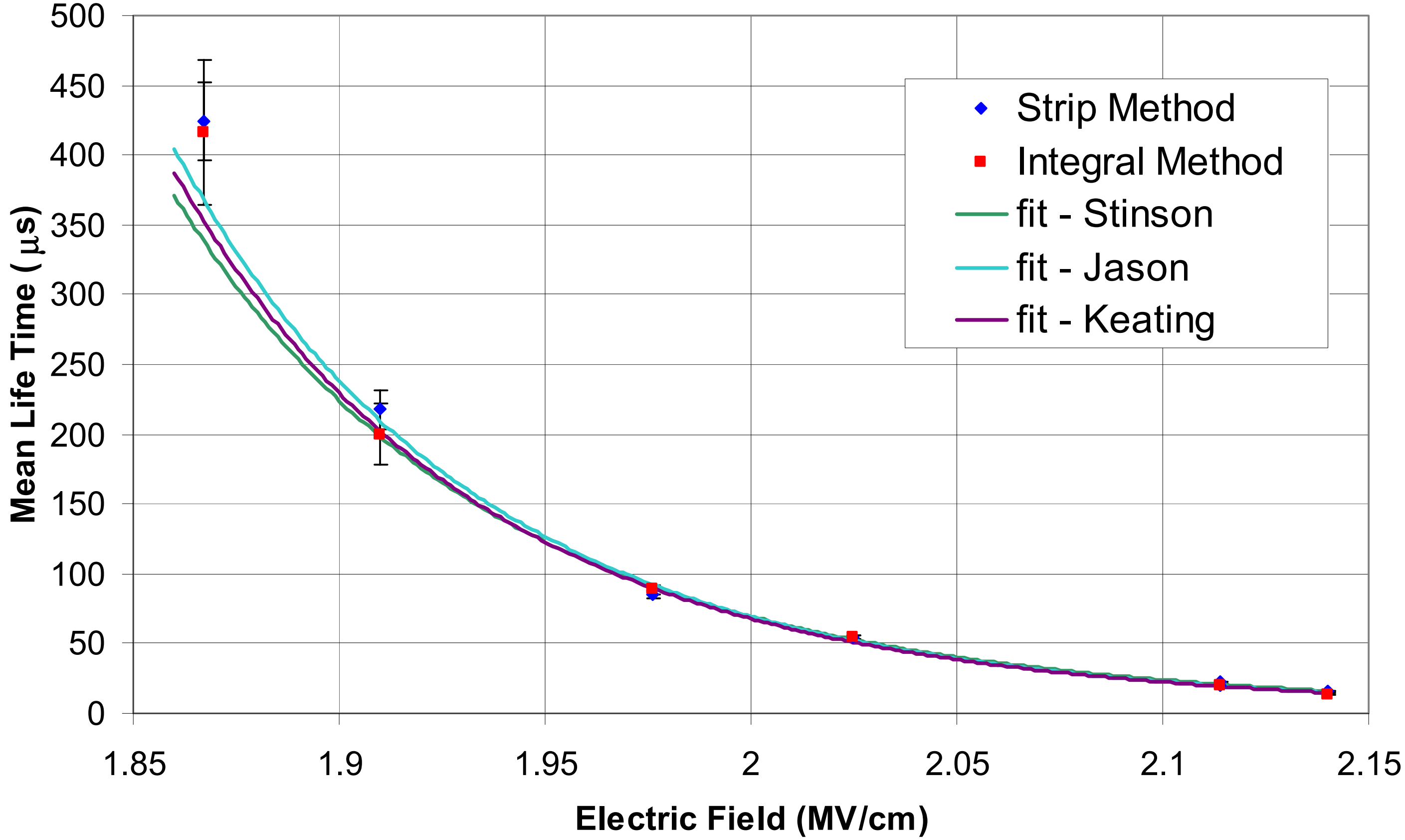
$$\tau = \frac{A_1}{E}\exp(\frac{A_2}{E})$$

- Get
  - $A1=2.47(\pm 0.09) \times 10^{-6}$ V·s/m
  - $A2=4.494(\pm 0.010) \times 10^{9}$ V/m
- Scherk result has
  - $A1=2.66 \times 10^{-6}$ V·s/m
  - $A2=4.47 \times 10^{9}$ V/m
- Without Stinson data, the results lie within experimental error
- Power of E in preexponential is best fit with unity
  - Poor χ^2 for zero power
  - Also poor fit (with Stinson data) for power of 2

Stinson experiment at TRIUMF was at 50 MeV



Similar later results by Keating et al. at LAMPF using Gypsy and incidental to other H^- measurements



Conclude

- **Measurements and theory provide accurate enough results for most applications**
- **Exponent in theoretical formula determines behavior for quick calculation scaling inversely as p x B**
  - **Note however that this scaling is not quite right since the results are in the rest frame and a Lorentz transform modifies this result in the pre-exponential. E.g., fractional loss/meter is**

$$\frac{B}{A_1}\exp\left(-\frac{A_2}{\beta\gamma c B}\right)$$

- **Results are consistent with behavior of stripping in PSR two stage injection scheme**
- **797 MeV, 3.8 kG (LANSCE minimal loss practice) and 8.00 GeV, 670 G give about same stripping rate of ~1.5x10^{-6} /m**