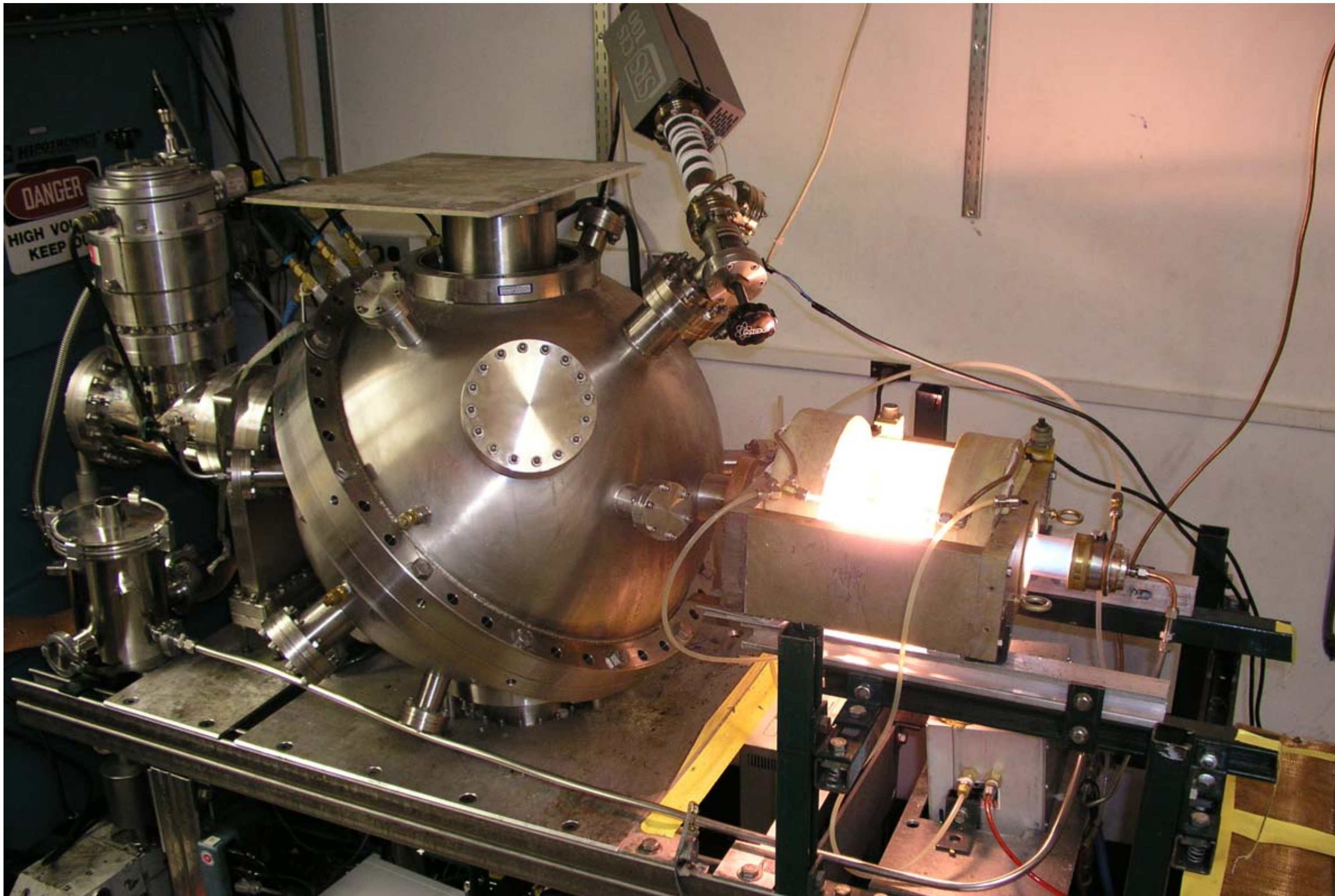
# Progress in Research on $^{3}He(^{3}He,2p)^{4}He$ Fusion Reactions at UW-Madison



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# Overview

- Theoretical requirements to observe $^{3}He(^{3}He,2p)^{4}He$ reactions
- Experimental capabilities
  - Helicon Helium ion source
  - IEC operation
  - *Current Effort--Low noise proton counting*
    - *Present detection system*
    - *Preliminary $^{3}He$ results*
    - *Intended improvements*
- Summary



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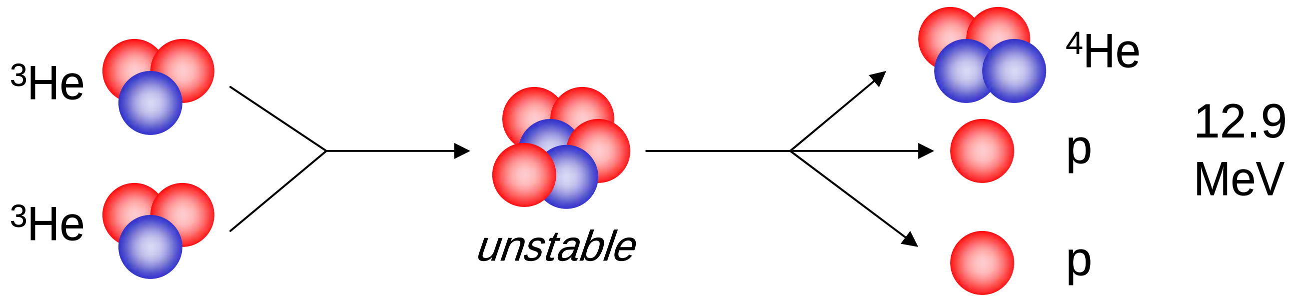
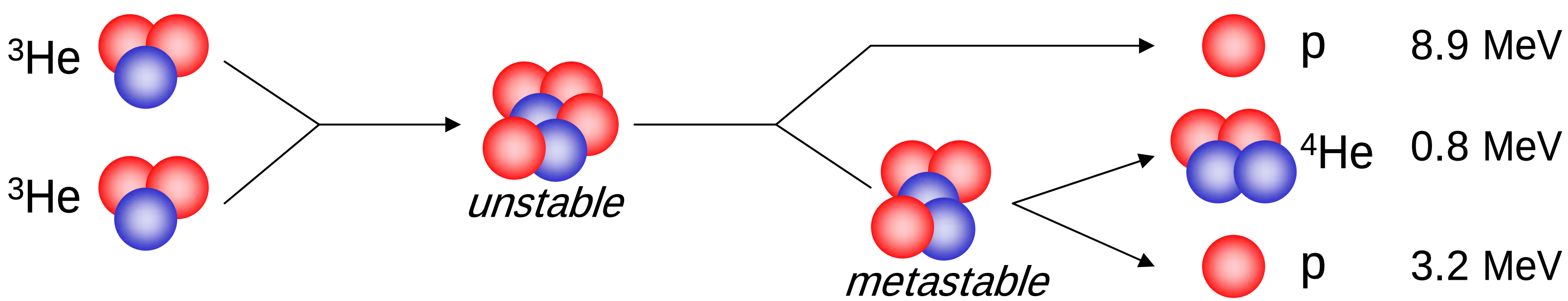
# $^3He(^3He,2p)^4He$ Reaction Overview




Most of the time, this reaction is a three body reaction, generating a continuum of particle energies




Sometimes, a resonance occurs generating a pair of two-body decays, which gives the reaction products discrete energies



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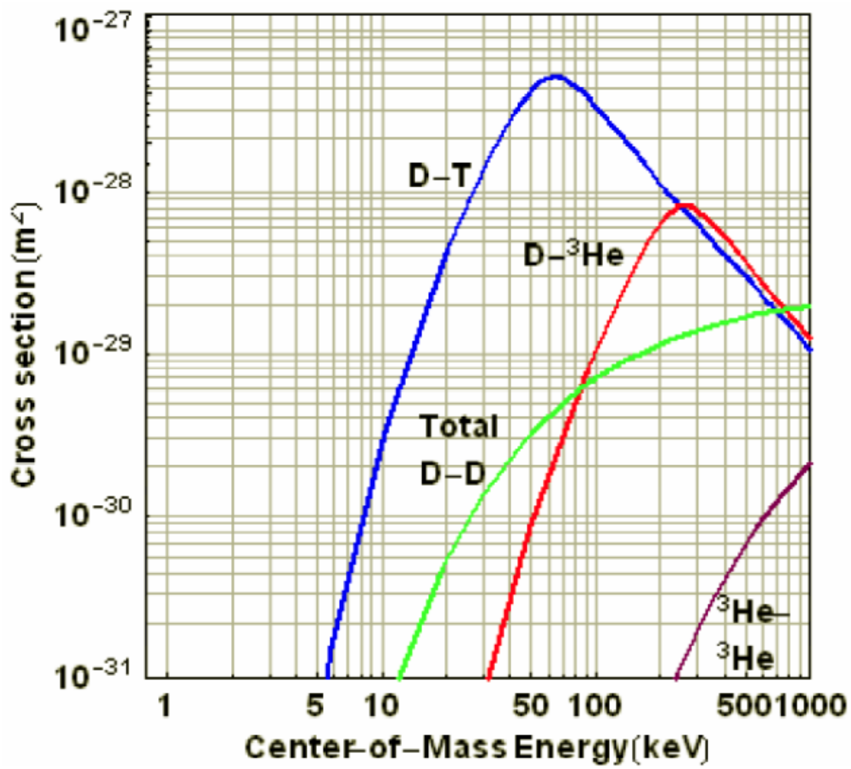
# Fusion Cross Section Indicates High Energy Needed to Observe $^3He(^3He,2p)^4He$ Reactions




- *Operation at high cathode voltage and low background pressure required*



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# High Density Ion Source Required for Desired Operating Conditions

- Pressure differential between source and IEC must be > 10:1 if the source pressure is 0.5-1 Pa in He gas
- Exit hole must be ~ 1 cm$^2$ to maintain this differential with our current configuration
- Bohm criterion sets maximum ion current versus source density

$$I_B \sim nqA\left(\frac{k_b T_e}{m_i}\right)^{\frac{1}{2}}$$

- Helicon source has highest available density for steady state plasma



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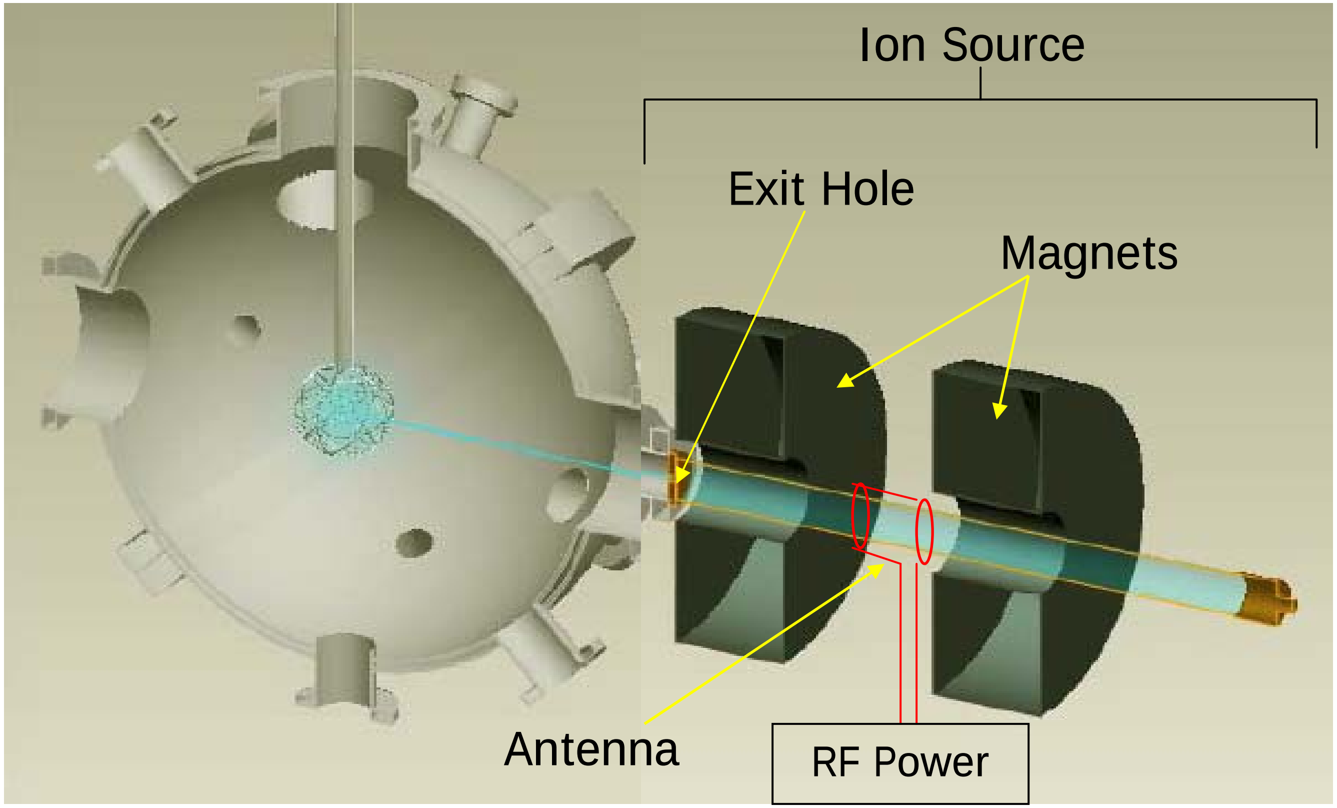
# Schematic of Ion Source Attached to IEC



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# Ion Source has been Developed for $^3$He Experiments

- Can provide sufficient current to max out our power supply (~75 mA)
  - More powerful RF supply (3 kW) has allowed higher intensity discharges (> $10^{19}$ particles/$m^3$)
  - Improvements to source geometry have allowed a higher plasma density at the exit hole
- Source can operate for hours at a time
  - Water cooling systems installed on all heat sensitive components
  - Heat shields added to protect o-rings from UV and light from the plasma
- Can operate in the desired pressure range of ~0.03 Pa in $^3$He


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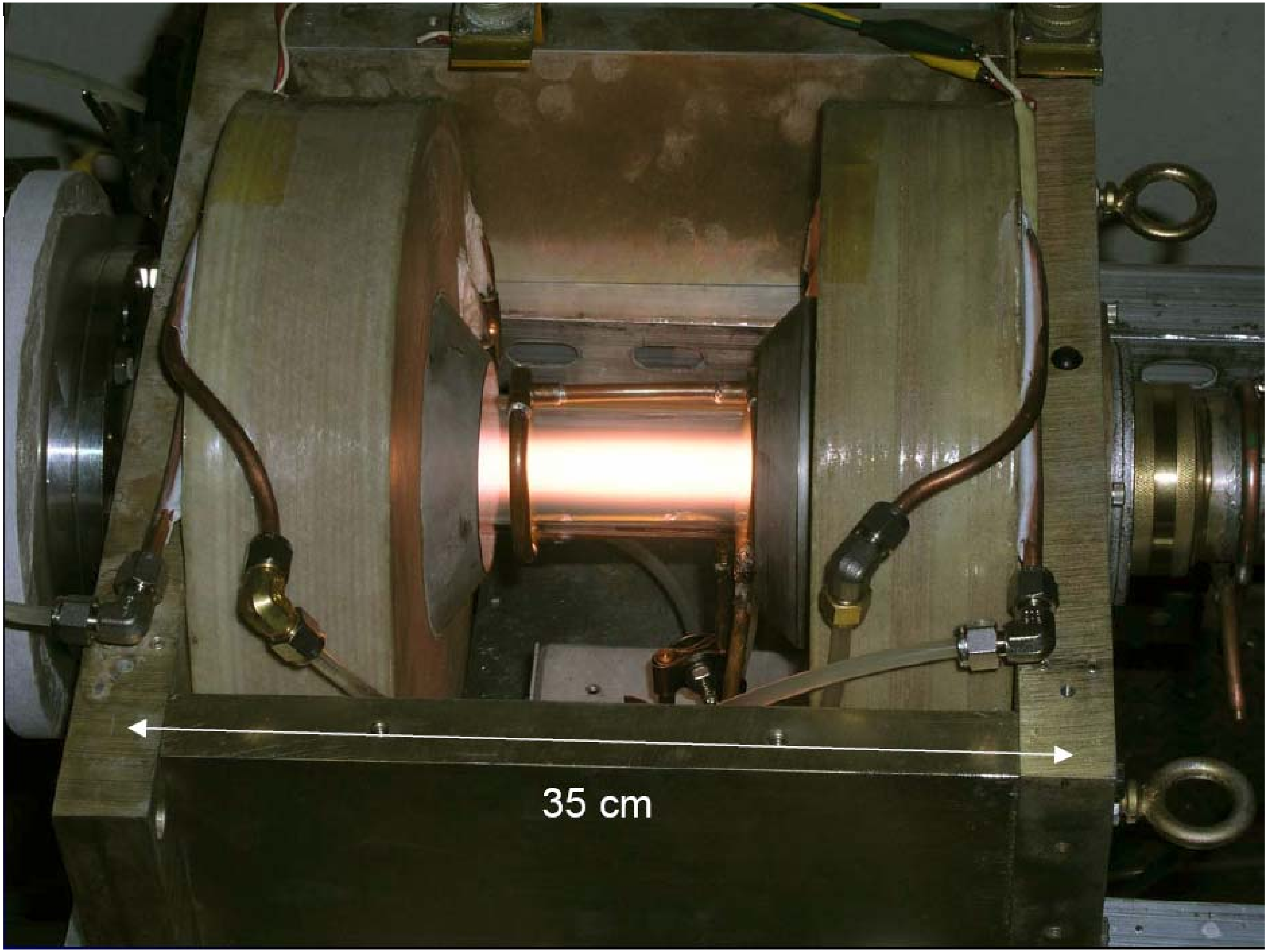
# Ion Source in Operation—$^4$He Gas



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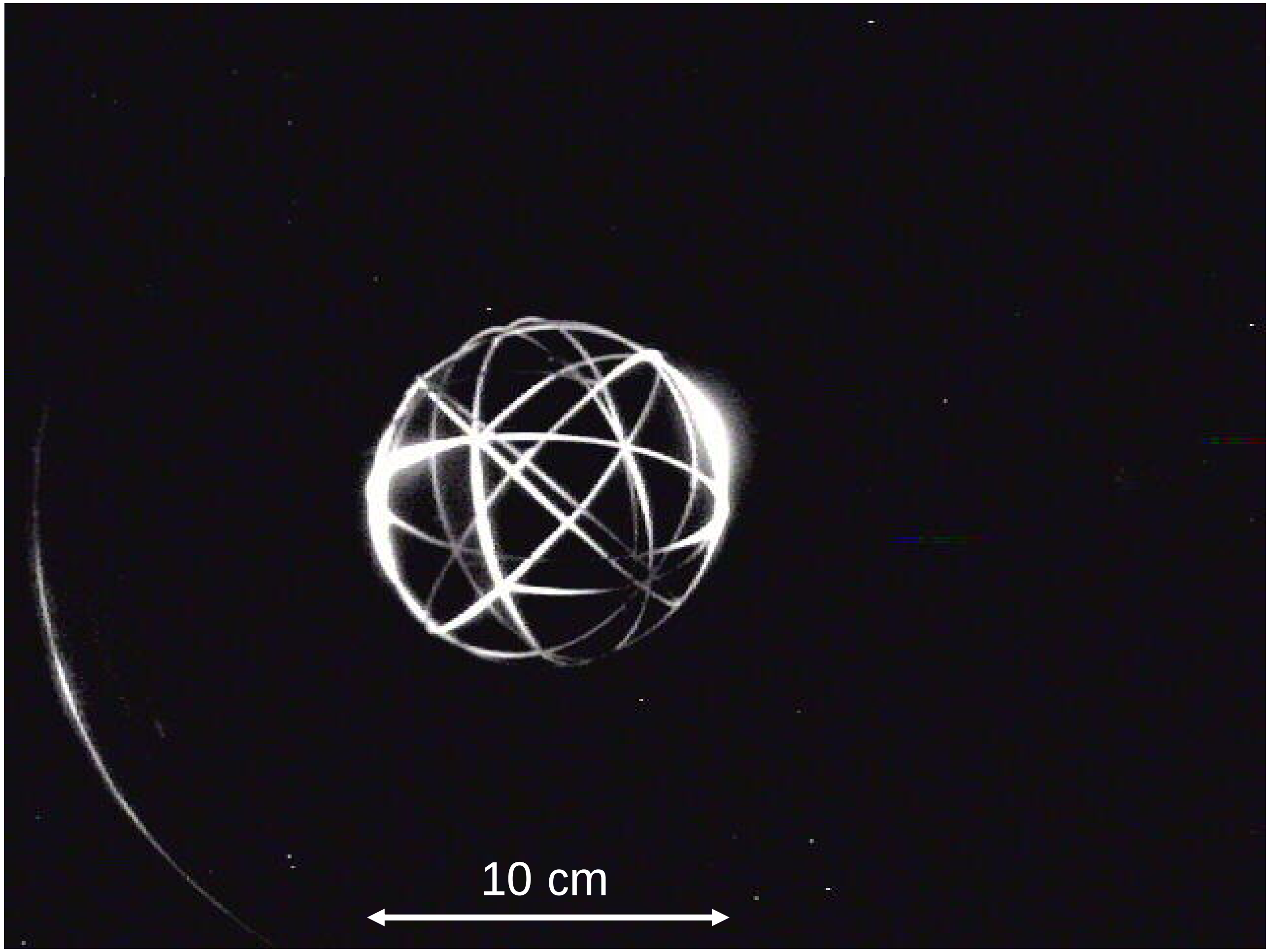
# IEC Performance has Reached Voltages Necessary for $^3He(^3He,2p)^4He$

- Maximum voltage achieved - 170 kV
- Maximum sustained voltage (for 900 seconds) – 150 kV
- Typical repeatable voltages have been 130 kV – 140 kV
- About a dozen $^3He$ runs have been done at these conditions, and half of these with direct comparison between $^3He$ and $^4He$ fuel
- Typical current ~ 30 mA at 0.03 Pa in He gasses

# IEC Cathode Operating with $^3He$ Gas—140 kV, 25 mA



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# Current Effort: Detection of $^3He(^3He,2p)^4He$ Protons in IEC Environment



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# Expected $^3He(^3He,2p)^4He$ Fusion Rate from Beam-Background Reactions

- Fusion rate for beam-background reactions:

$$F = \frac{n_b * I_{cath} * 2r_{cath}}{e(1-\eta^2)(1+\gamma_{eff})}\sigma(E)$$

Assumes all ions mono-energetic. $n_b$ is background gas density, $I_{cath}$ is measured cathode current, $r_{cath}$ is the cathode radius, $\eta$ is the cathode transparency, $\gamma_{eff}$ is the effective secondary emission coefficient, and $\sigma(E)$ is the fusion cross section.

- Assume $\eta$=0.94, $\gamma_{eff}$ ~ 3, $He^{1+}$ only
- Predicted fusion rate at 200 kV, 30mA, 0.04 Pa = $3*10^4$ reactions/s
- Detector rate in this case is ~ 10 cts / s
- Actual rate is considerably lower due to shielding and difficulties in reaching 200 kV with current apparatus
- ***Low count rate requires low background system***

# IEC Operating Conditions Create High-Noise Environment

- So far, operation above 100 kV has resulted in repeated arcing
  - Arcs generate EMP which causes broad spectrum noise on all electronically sensitive instruments (eg. Detectors, cameras…)
  - Arcs also cause power supply shutdowns, causing large mechanical contactors to open which generates broad spectrum noise
- Noise levels generated at conditions needed for $^3He$ fusion have exceeded the detection rate in the past

➢ *Tool needed to prevent detector from counting during unstable operation*



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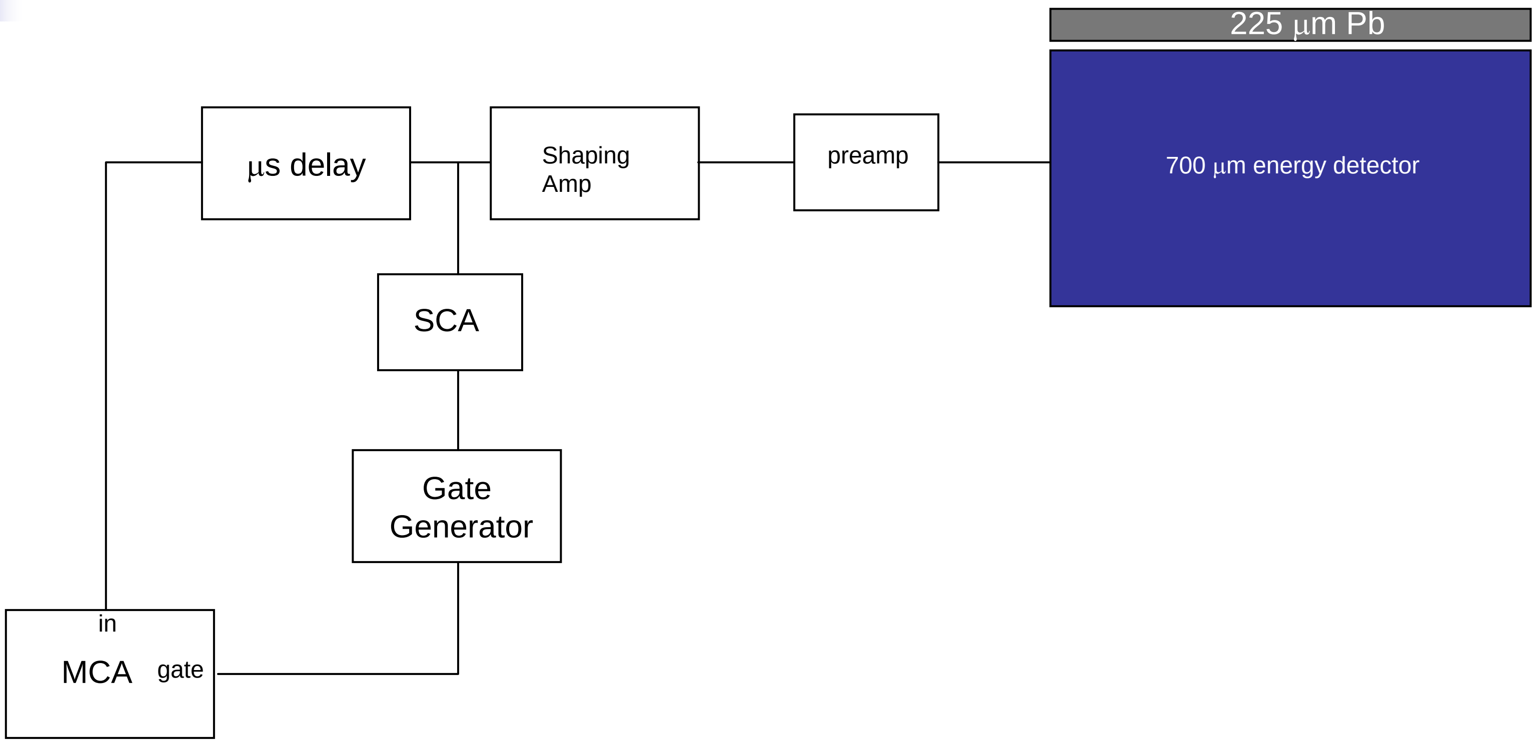
# First Generation Arc Suppression




- This didn't work very well—sometimes arcs generated signals that did not have a high energy component



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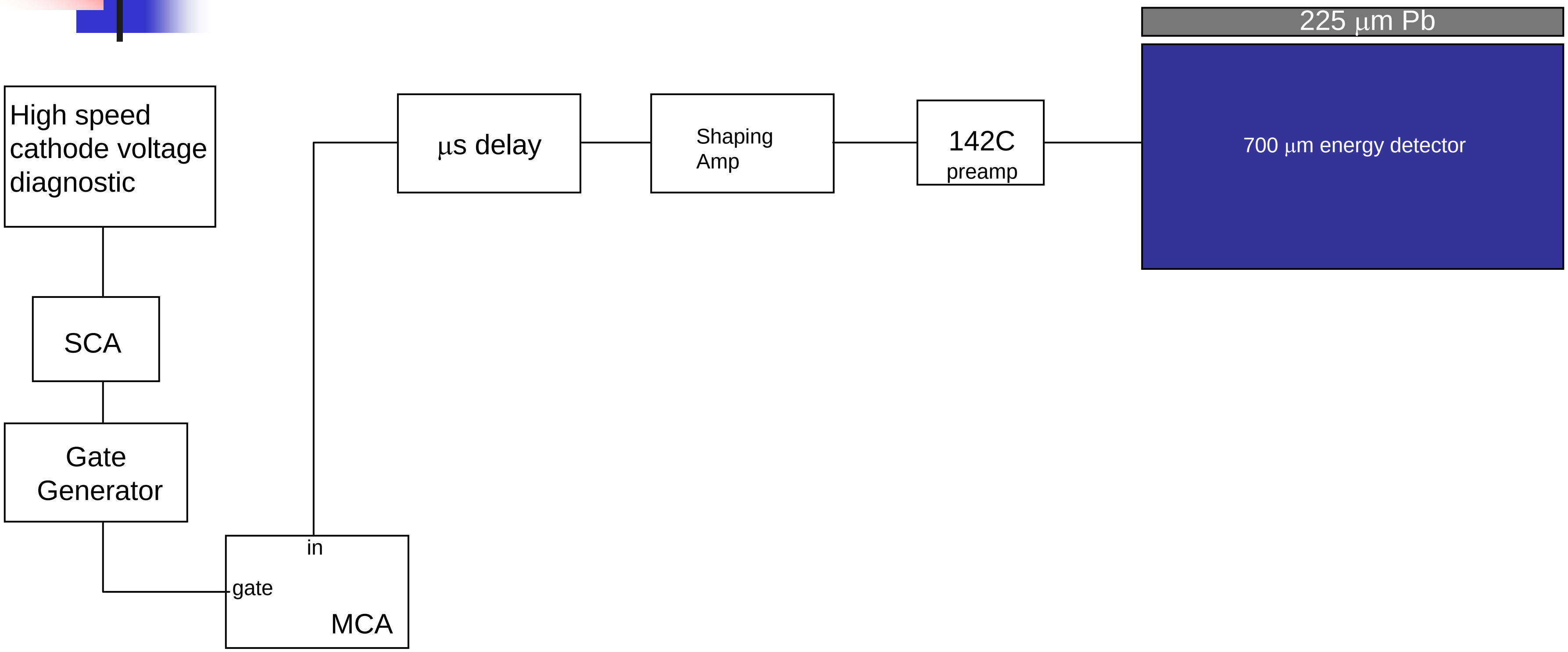
# Second Generation Arc Suppression Eliminates Arc Noise




- This works well—noise due to high voltage arcing and shutdowns is effectively eliminated



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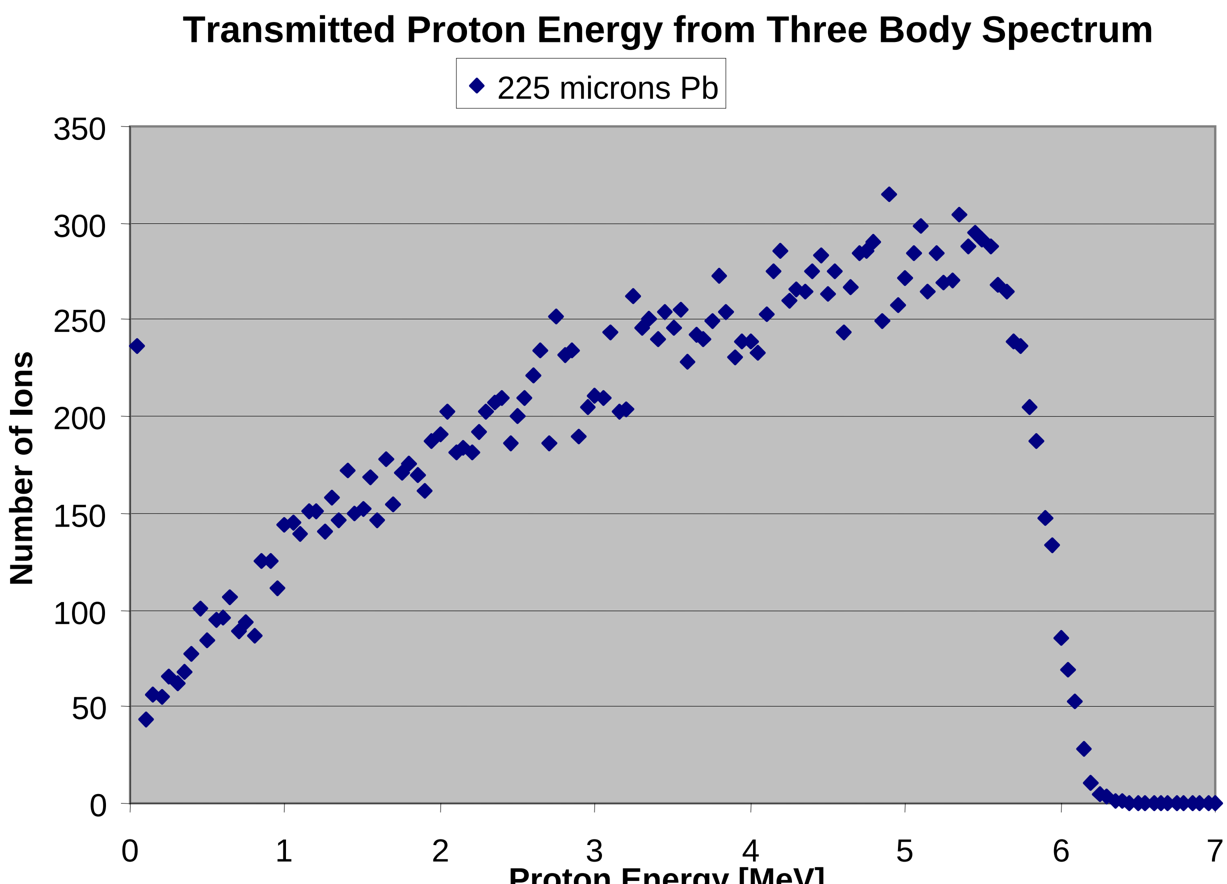
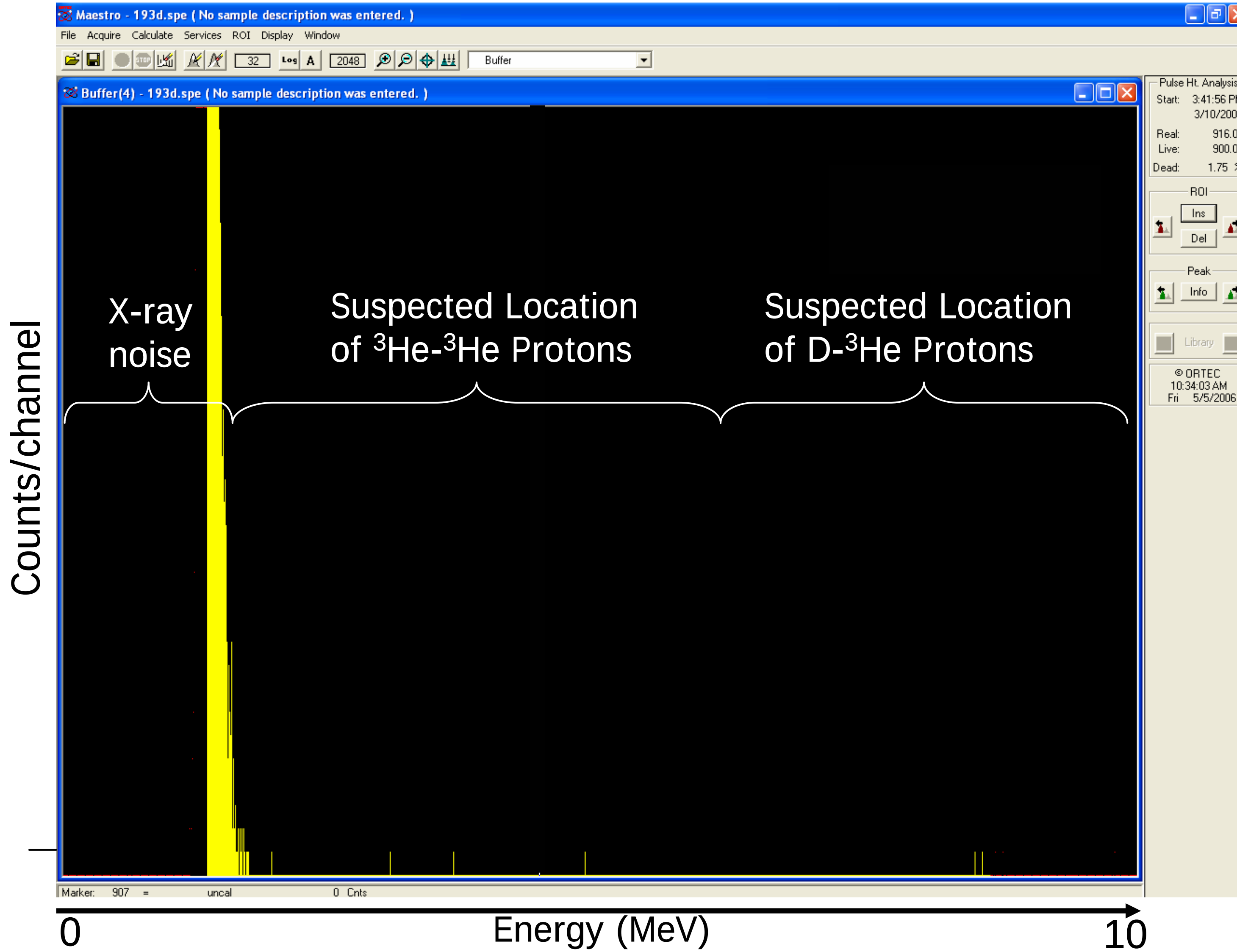
# Predicted Spectrum for $^3He(^3He,2p)^4He$ Reactions with Current Detector Setup




About 25% of incident protons make it through 225 um of lead

# Actual Spectra—$^4$He at 140 kV 25 mA 900 sec with 2$^{nd}$ Generation Arc Suppression





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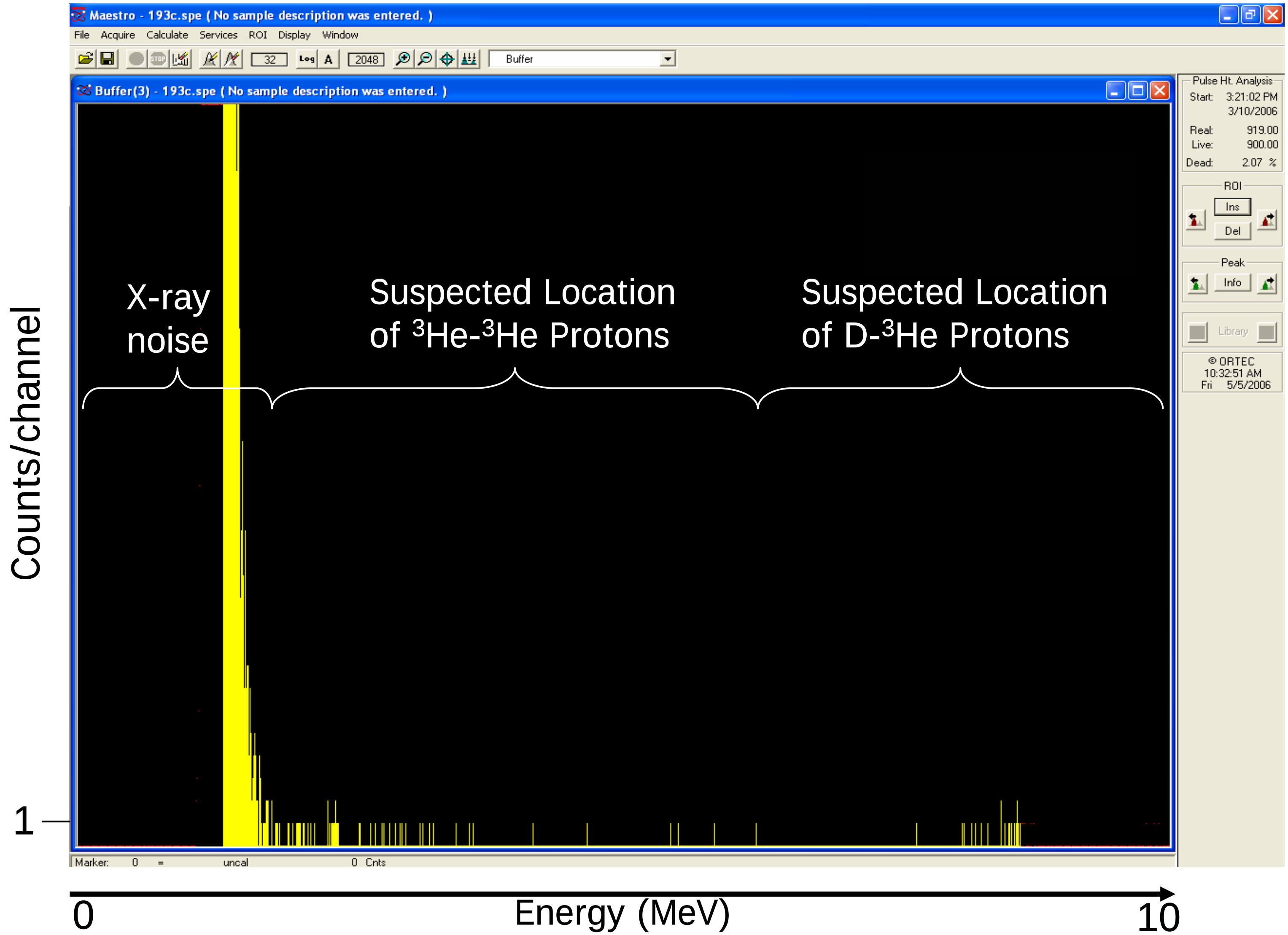
# Actual Spectra—$^3$He at 140 kV 25 mA 900 sec with 2$^{nd}$ Generation Arc Suppression




May 10, 2006 US-Japan Workshop VIII
Presented at Kansai University

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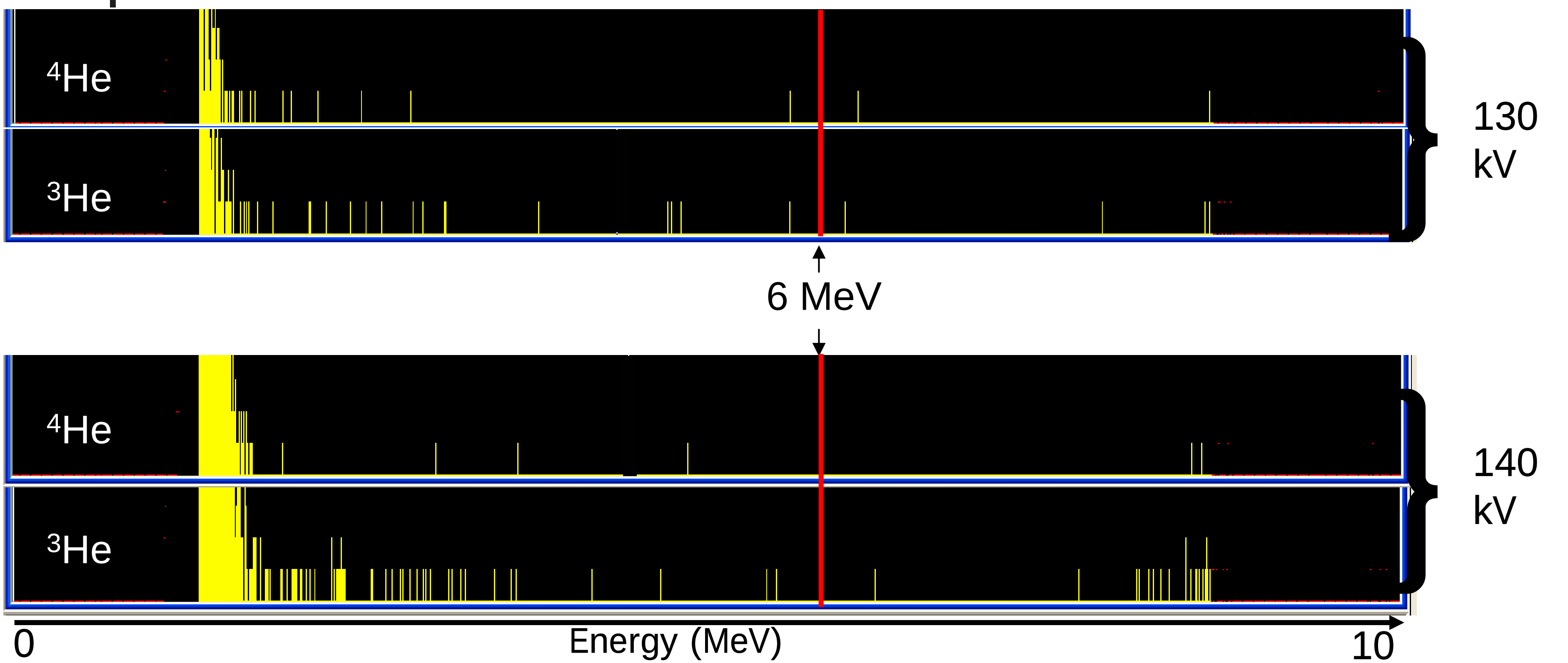
# Comparison of Measured Protons at 130 kV and 140 kV (25 mA, 900 s)



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# Detection has Come a Long Way—More can be Done

- Even though the arcs have been effectively suppressed, there are still multiple sources of noise
  - Background radiation
  - Pile-up noise
  - Induced radiation from surrounding experiments
  - Interference from D-$^{3}$He due to impurities containing the natural abundance of D (about 1 per 6000 H atoms)
- Third generation circuit will prevent all of these problems



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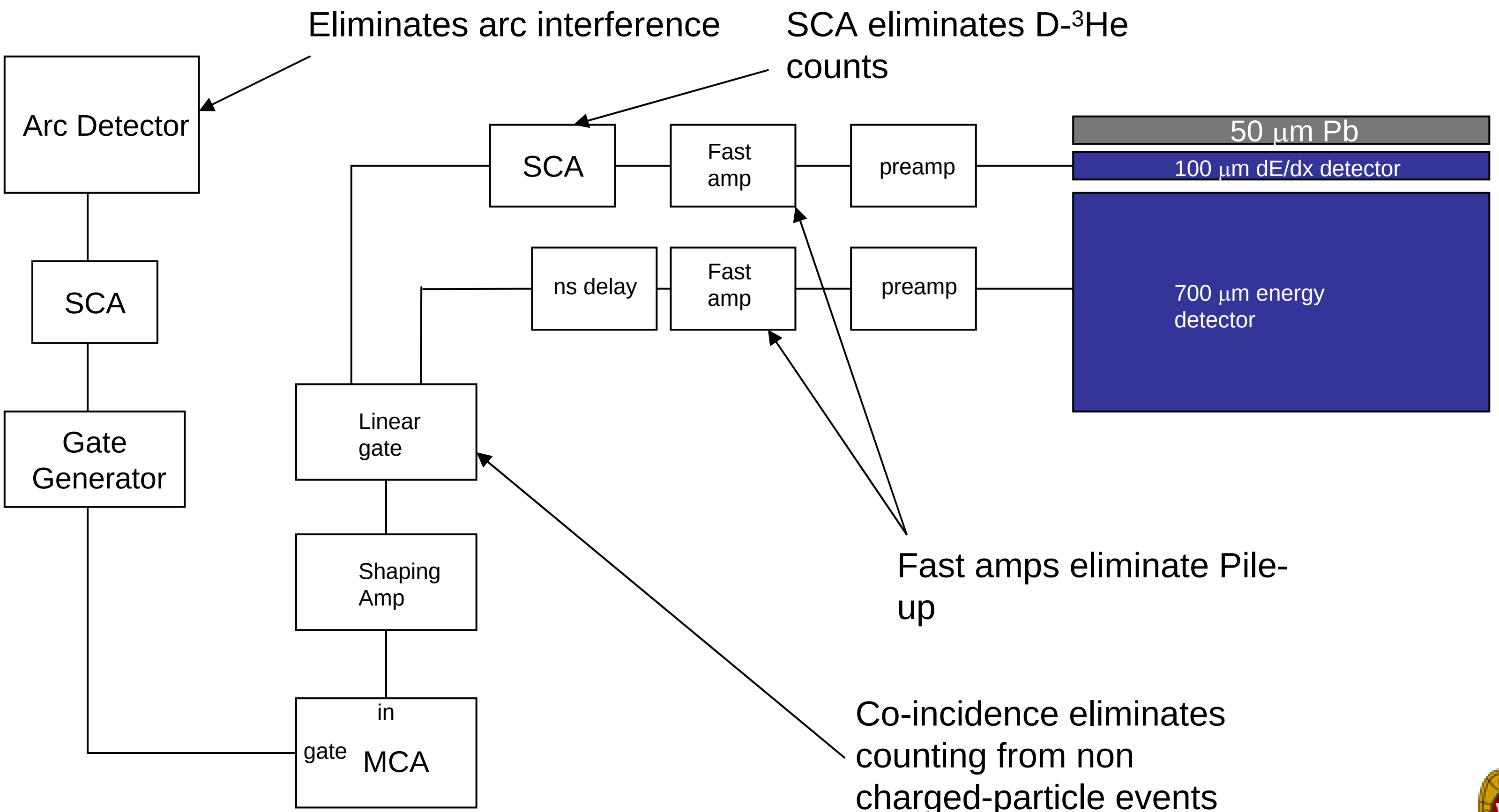
# Third Generation Arc Suppression Circuit



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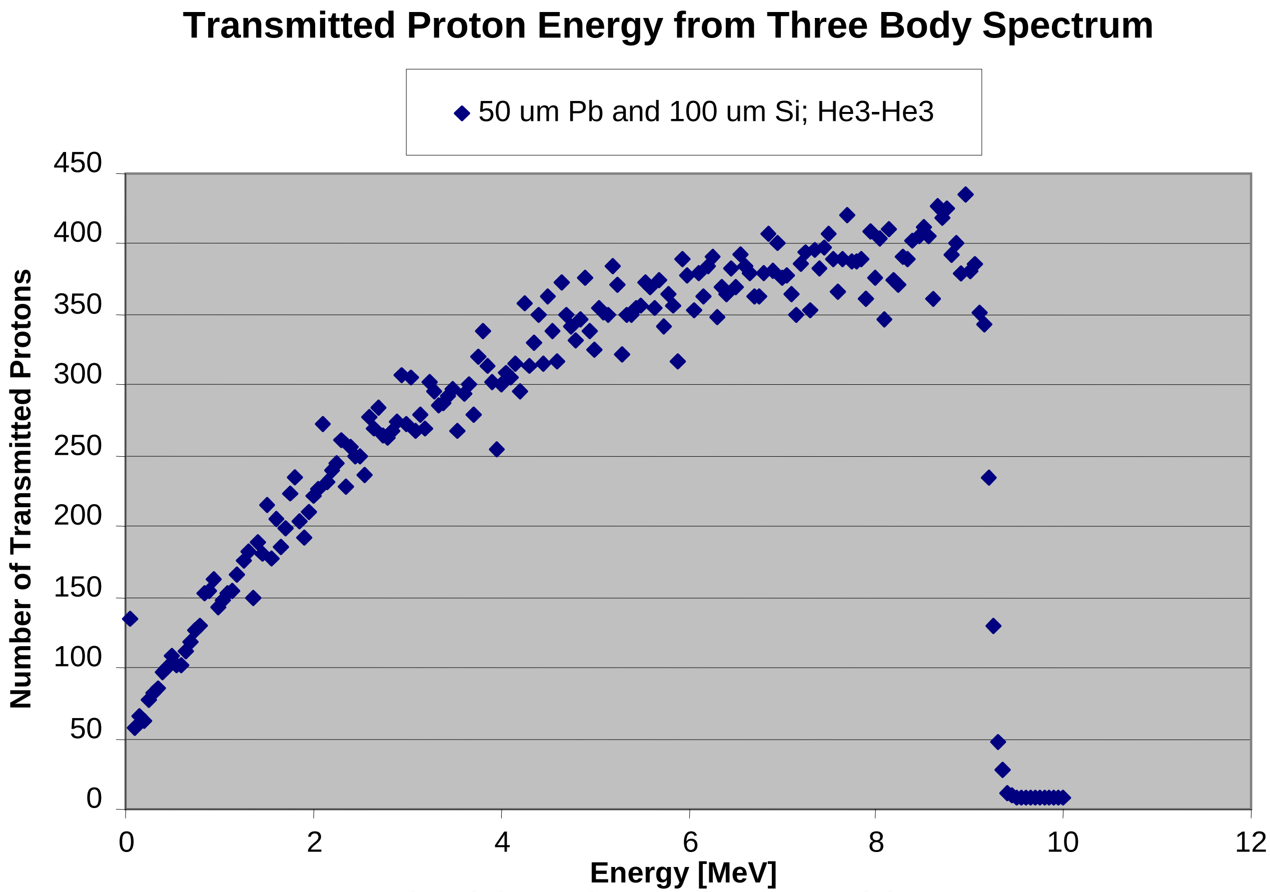
# Predicted Spectrum for $^{3}He(^{3}He,2p)^{4}He$ Reactions with Third Generation Detection Setup




55% of incident ions detected by new setup



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# Summary

- IEC operating conditions necessary to observe $^{3}He(^{3}He,2p)^{4}He$ reactions have been achieved routinely at 130-140 kV
- 2nd generation noise suppression system has been developed to greatly reduce noise at these conditions
- Preliminary results show a substantial increase in detected protons with $^{3}He$ gas versus $^{4}He$
- Third generation detector setup will allow data to be interpreted more clearly and with better statistics


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