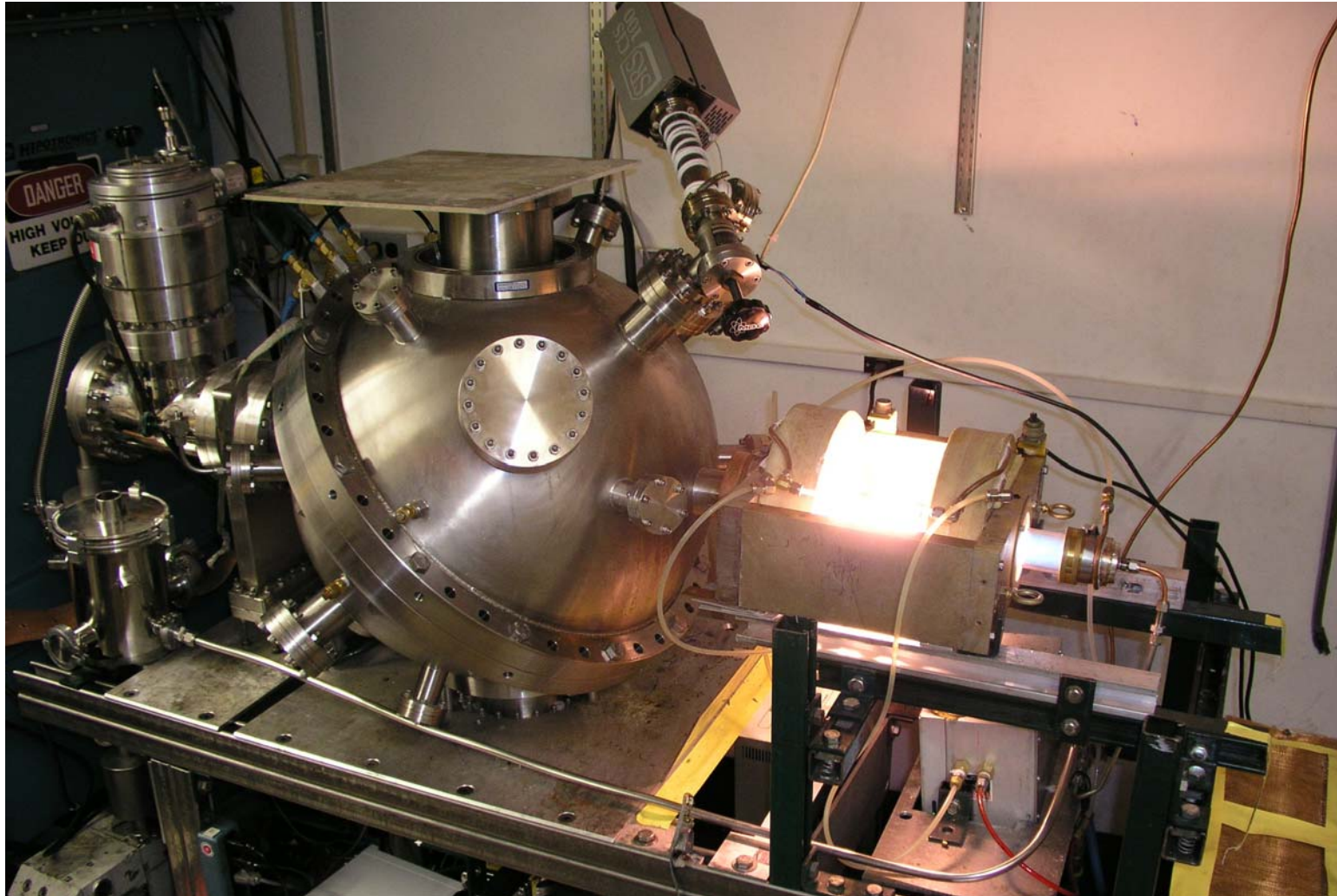


Progress in Research on ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ Fusion Reactions at UW-Madison



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

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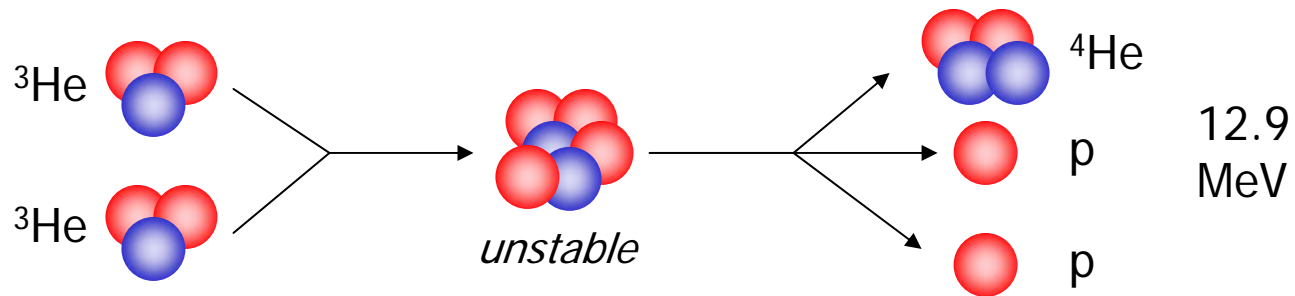


Overview

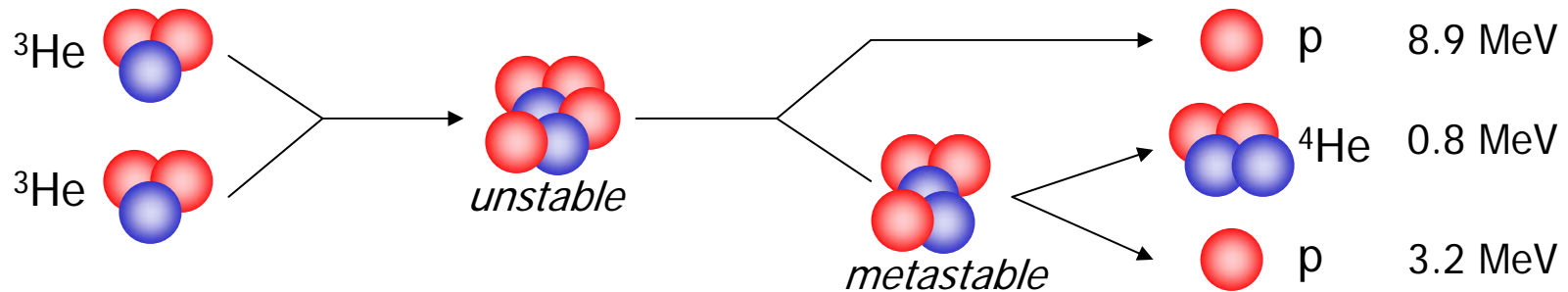
- Theoretical requirements to observe ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ reactions
- Experimental capabilities
 - Helicon Helium ion source
 - IEC operation
 - *Current Effort--Low noise proton counting*
 - *Present detection system*
 - *Preliminary ${}^3\text{He}$ results*
 - *Intended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



${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ Reaction Overview



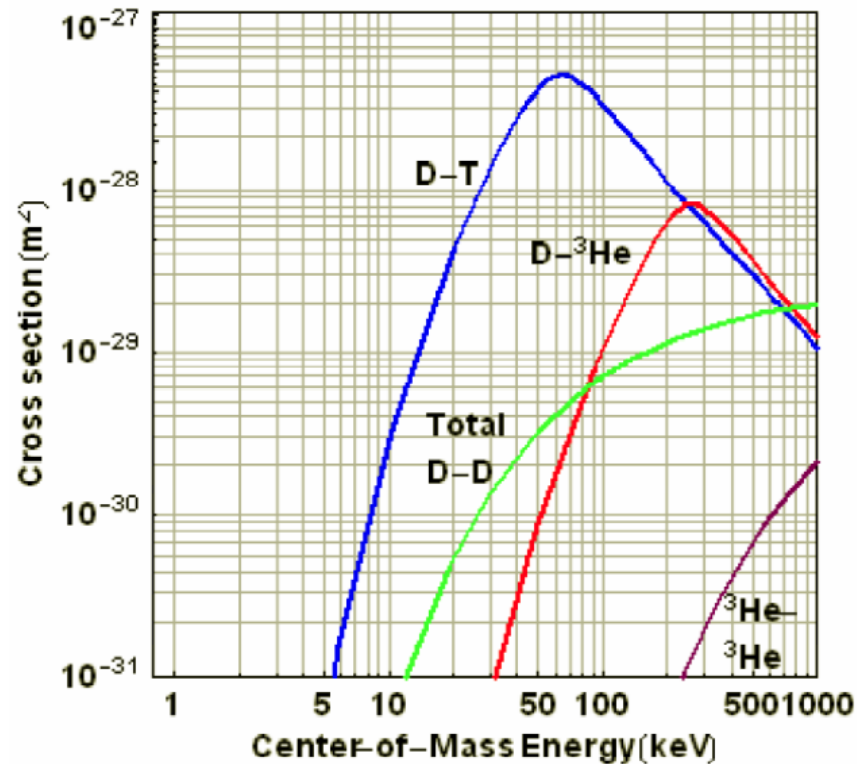
Most of the time, this reaction is a three body reaction, generating a continuum of particle energies



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



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



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



High Density Ion Source Required for Desired Operating Conditions

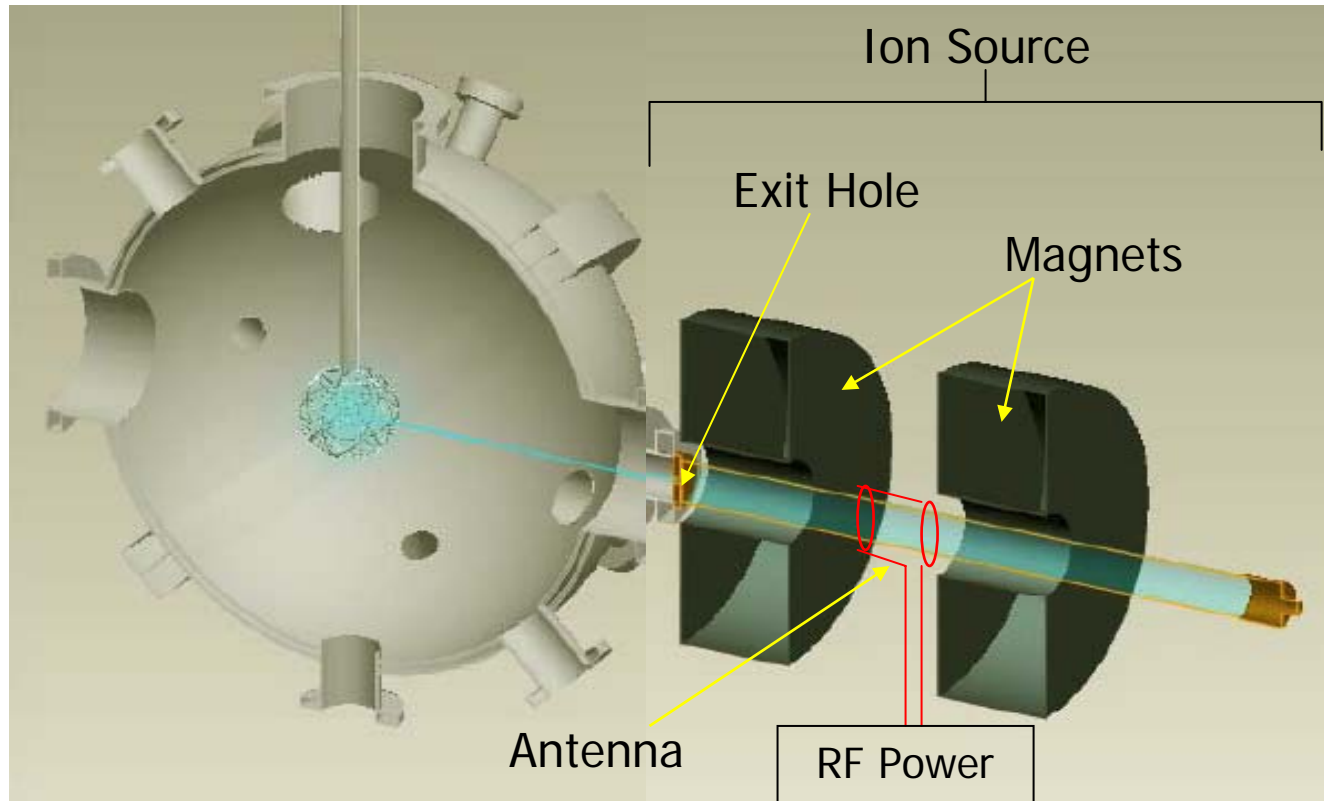
- Pressure differential between source and IEC must be $> 10:1$ if the source pressure is 0.5-1 Pa in He gas
- Exit hole must be $\sim 1 \text{ cm}^2$ to maintain this differential with our current configuration
- Bohm criterion sets maximum ion current versus source density

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

- Helicon source has highest available density for steady state plasma



Schematic of Ion Source Attached to IEC

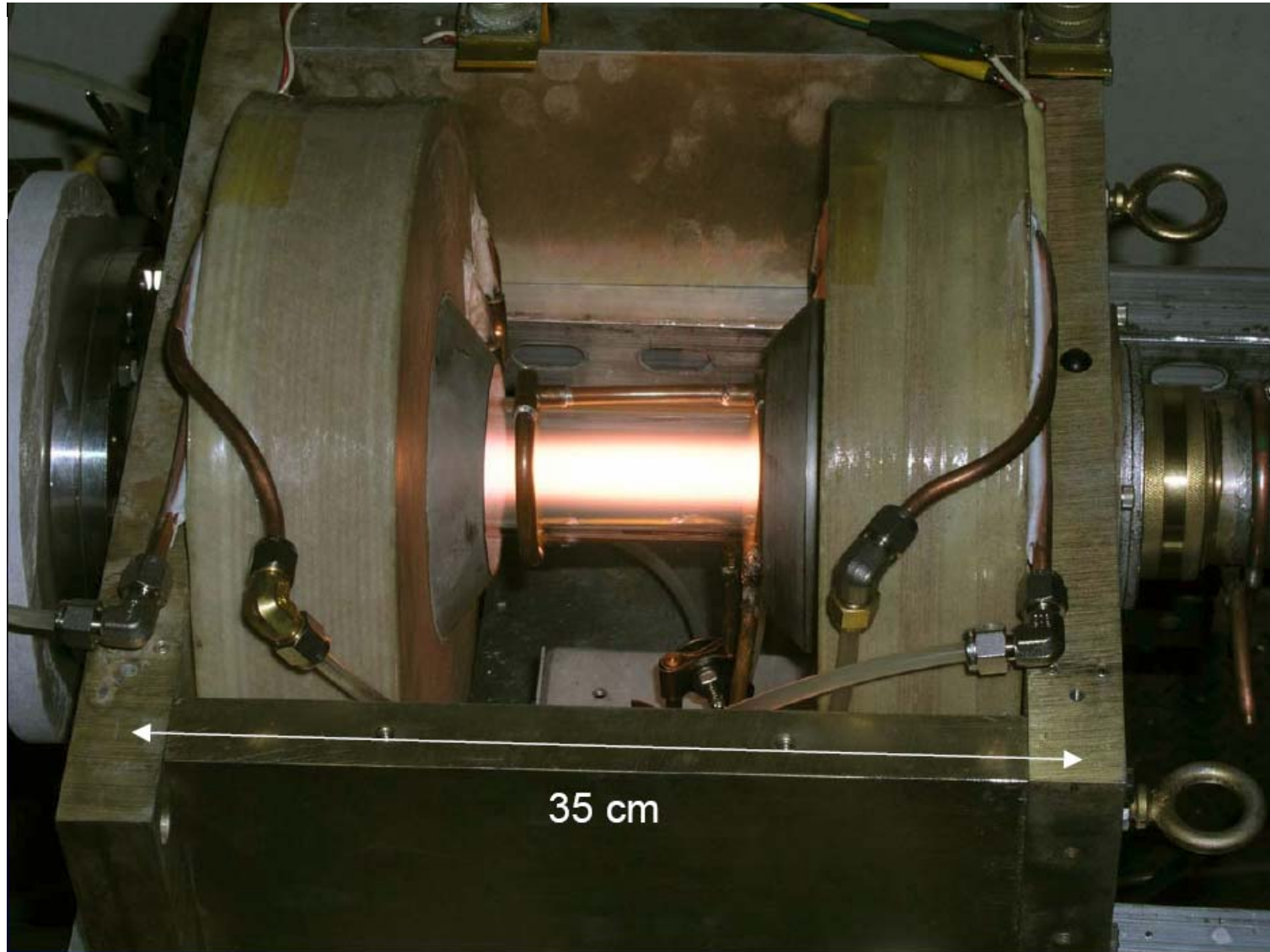


Ion Source has been Developed for ^3He Experiments

- 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/m³)
 - 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 ^3He



Ion Source in Operation— ^4He Gas



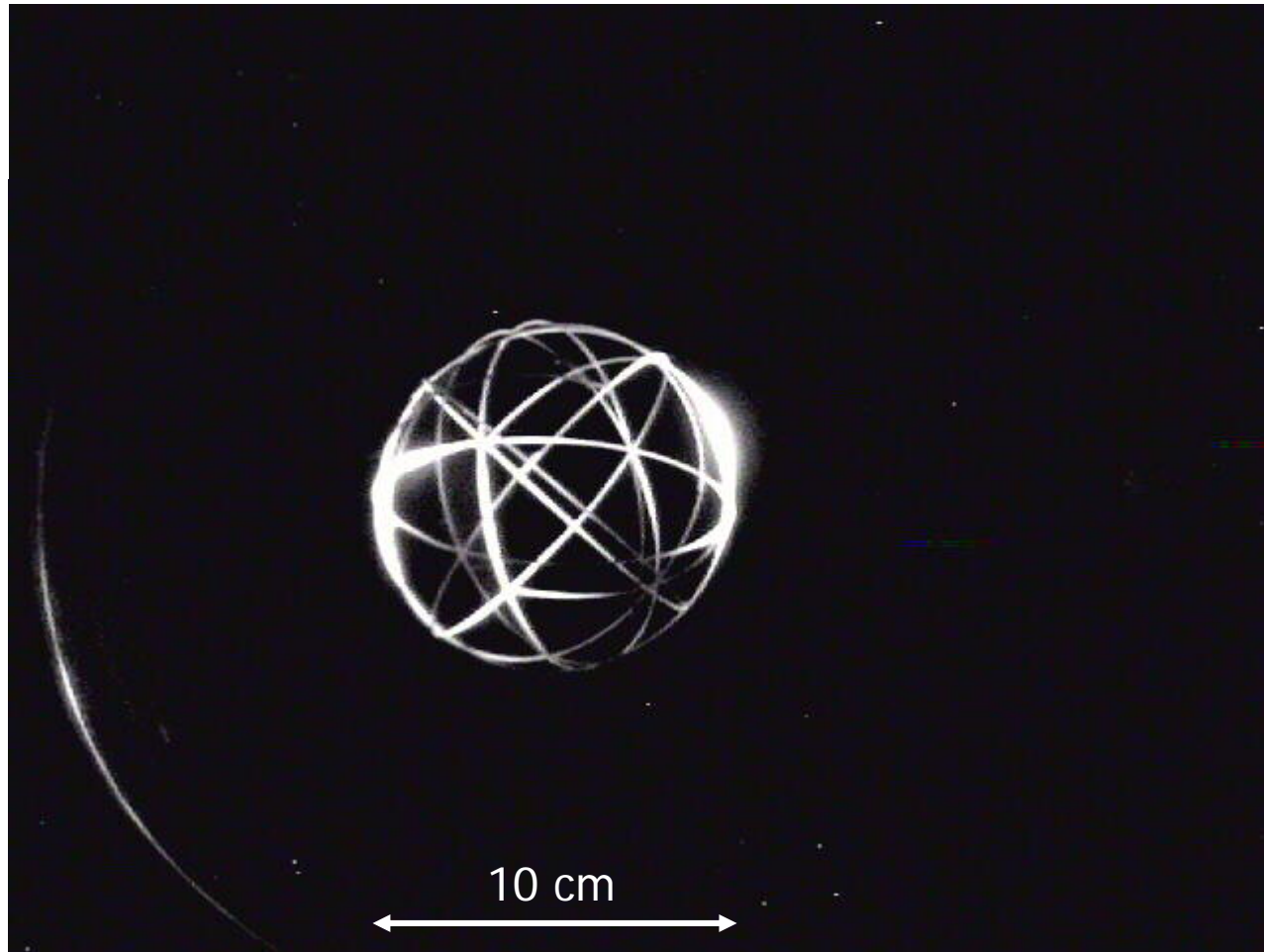
IEC Performance has Reached Voltages

Necessary for ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$

- 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 ${}^3\text{He}$ runs have been done at these conditions, and half of these with direct comparison between ${}^3\text{He}$ and ${}^4\text{He}$ fuel
- Typical current ~ 30 mA at 0.03 Pa in He gasses



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



Current Effort: Detection of ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ Protons in IEC Environment



Expected ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ 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, η is the cathode transparency, γ_{eff} is the effective secondary emission coefficient, and $\sigma(E)$ is the fusion cross section.

- Assume $\eta=0.94$, $\gamma_{eff} \sim 3$, He^{1+} only
- Predicted fusion rate at 200 kV, 30mA, 0.04 Pa = $3 \cdot 10^4$ 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***

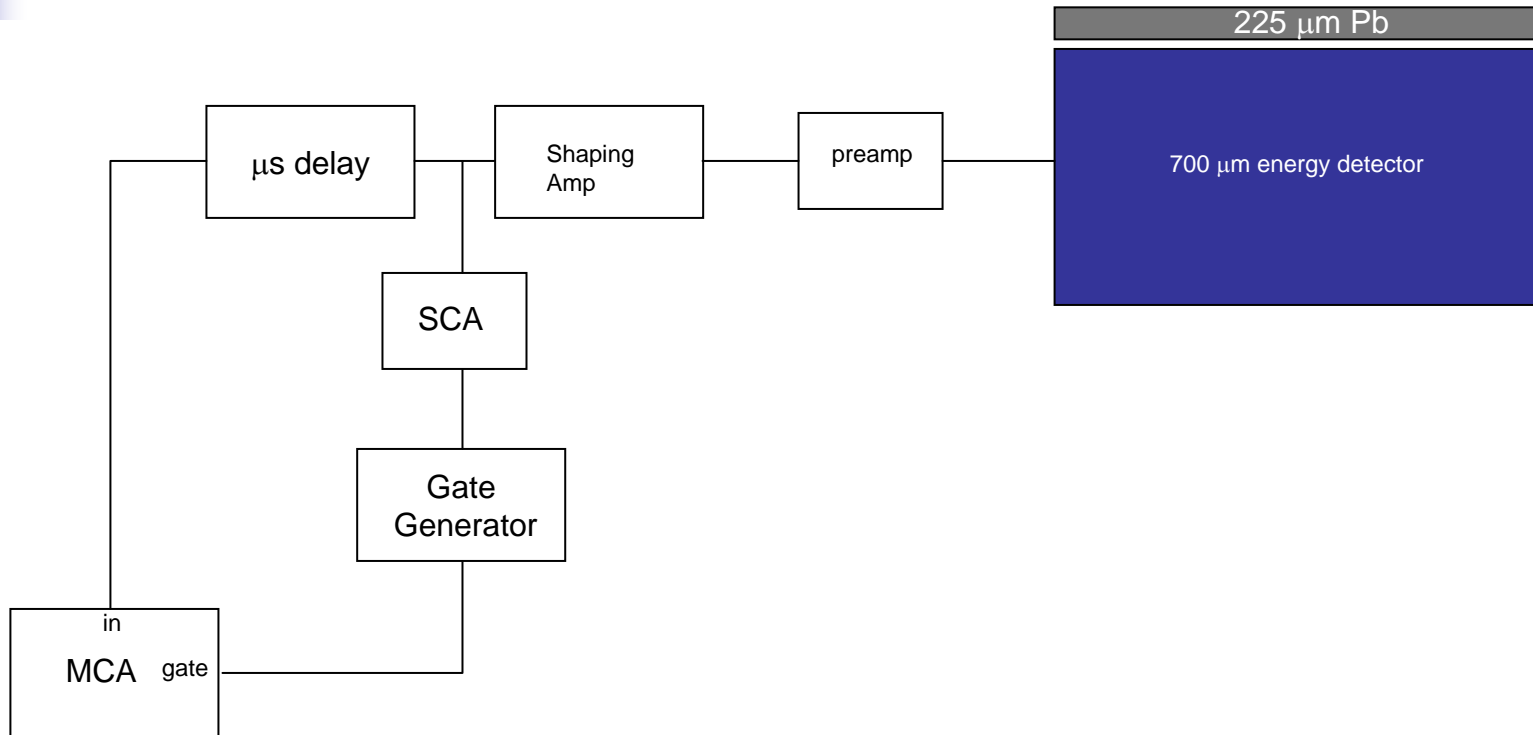


IEC Operating Conditions Create High-Noise Environment

- 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*



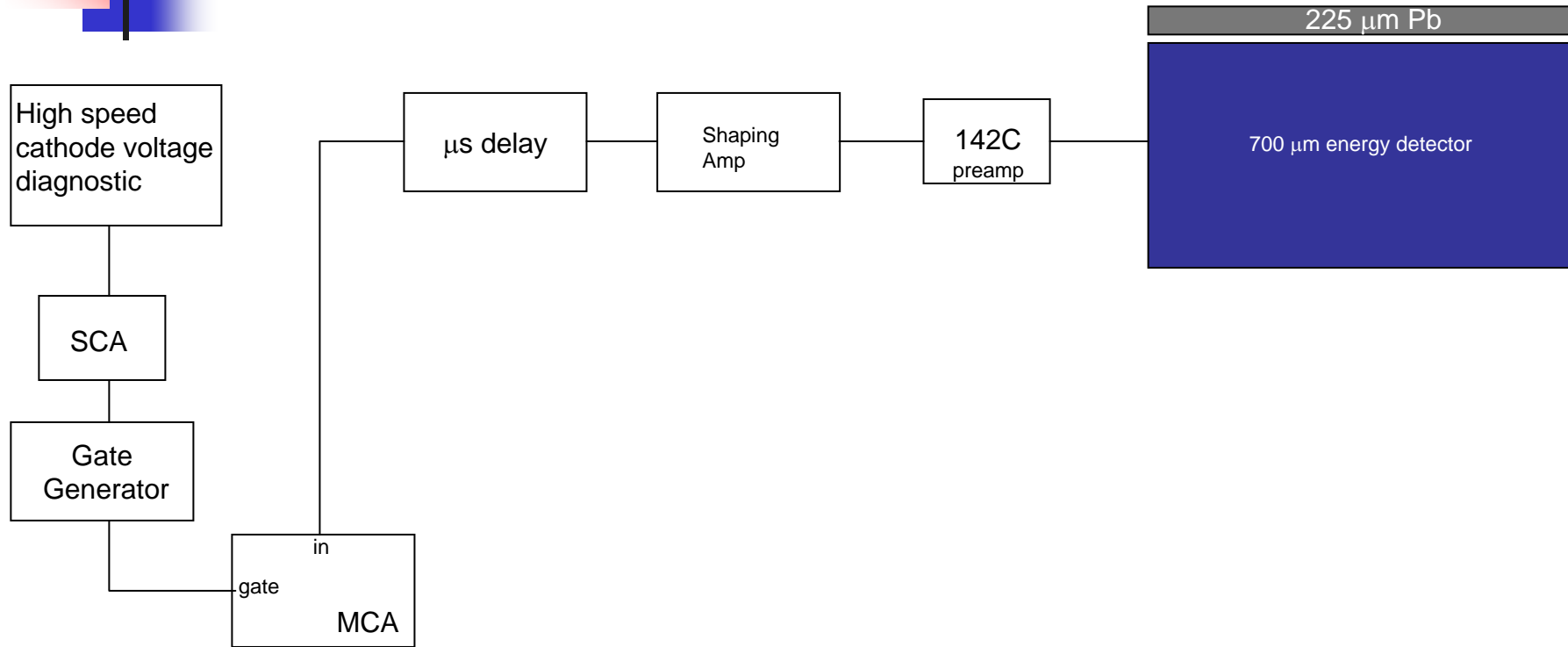
First Generation Arc Suppression



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



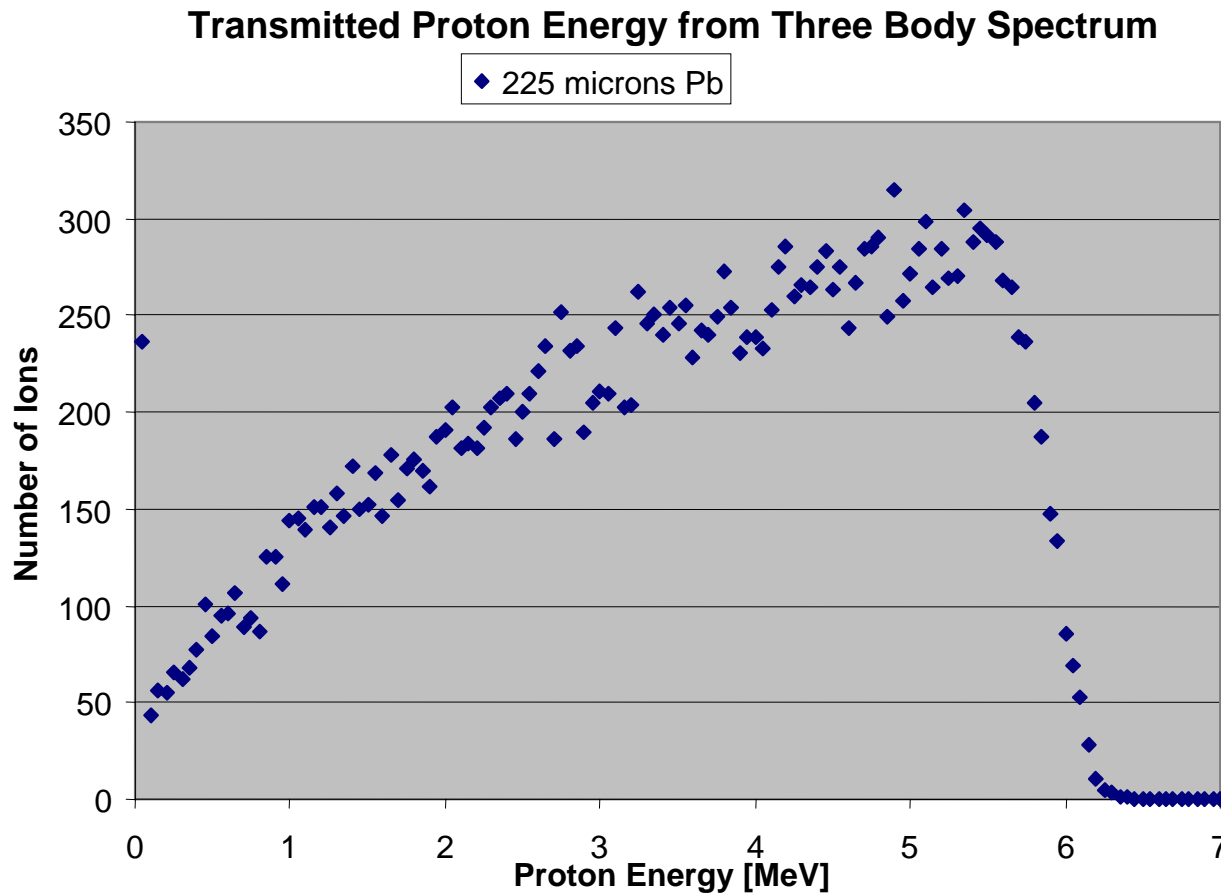
Second Generation Arc Suppression Eliminates Arc Noise



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



Predicted Spectrum for ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ Reactions with Current Detector Setup



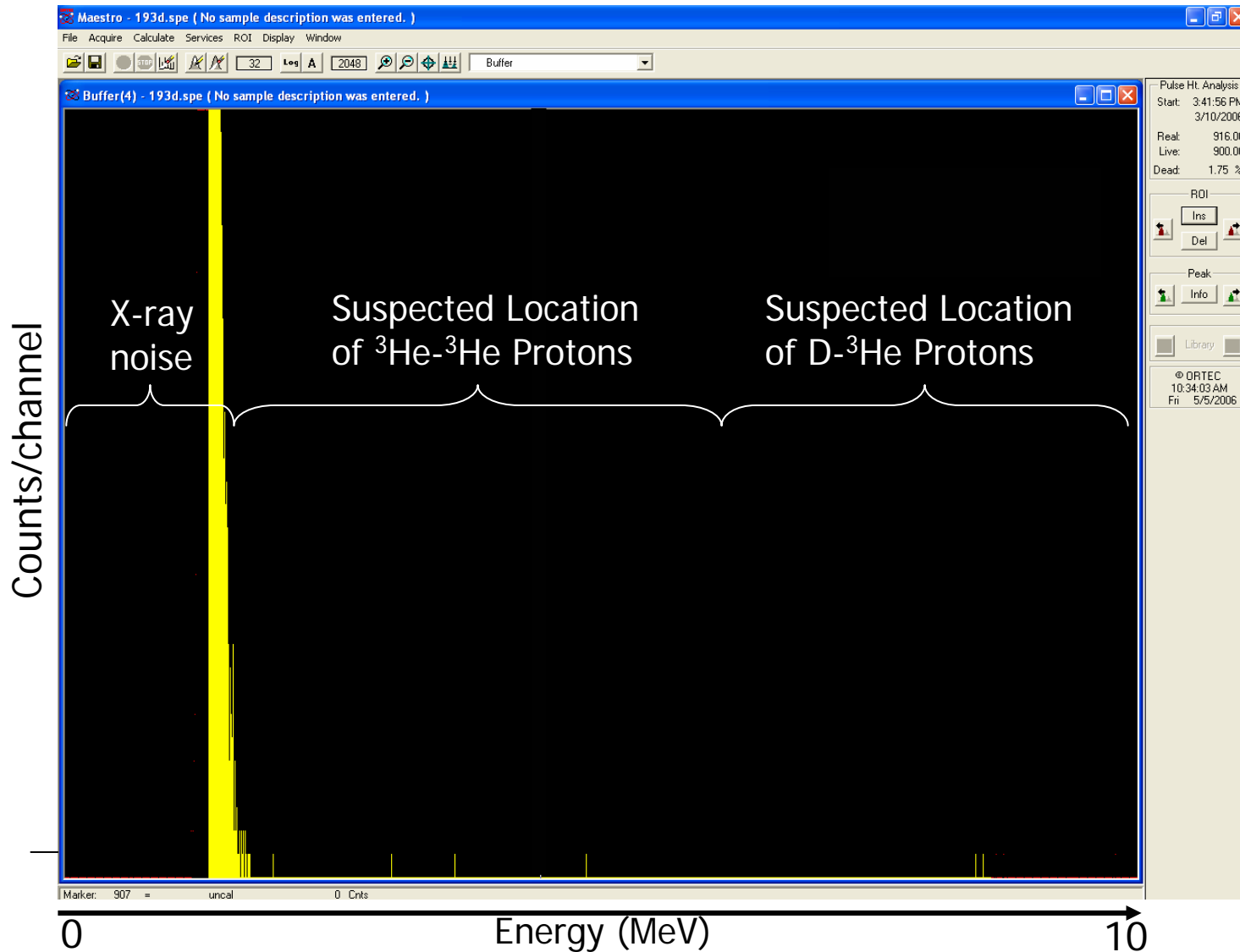
About 25% of incident protons make it through 225 um of lead

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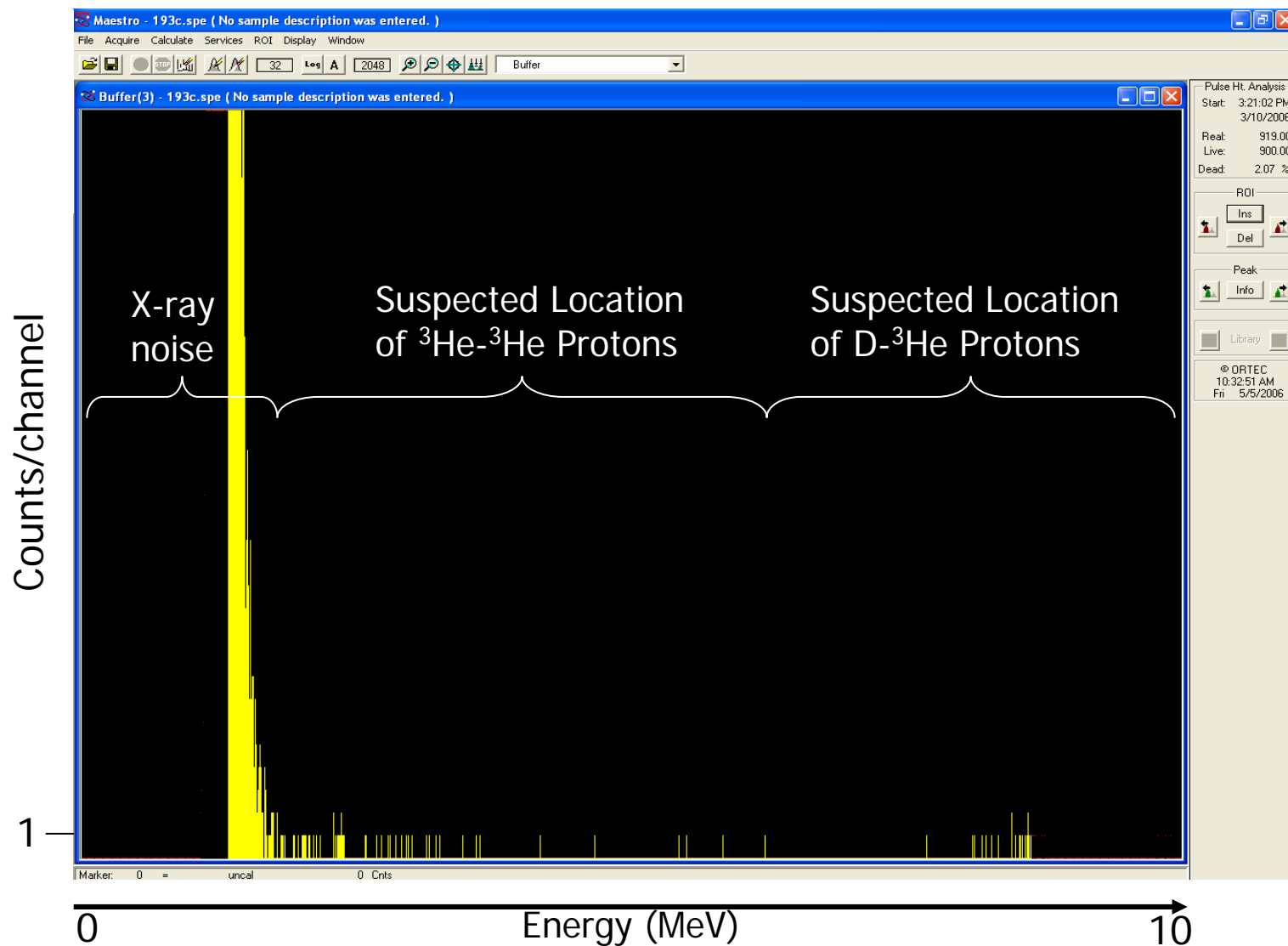
Actual Spectra— ^4He at 140 kV 25 mA 900 sec with 2nd Generation Arc Suppression



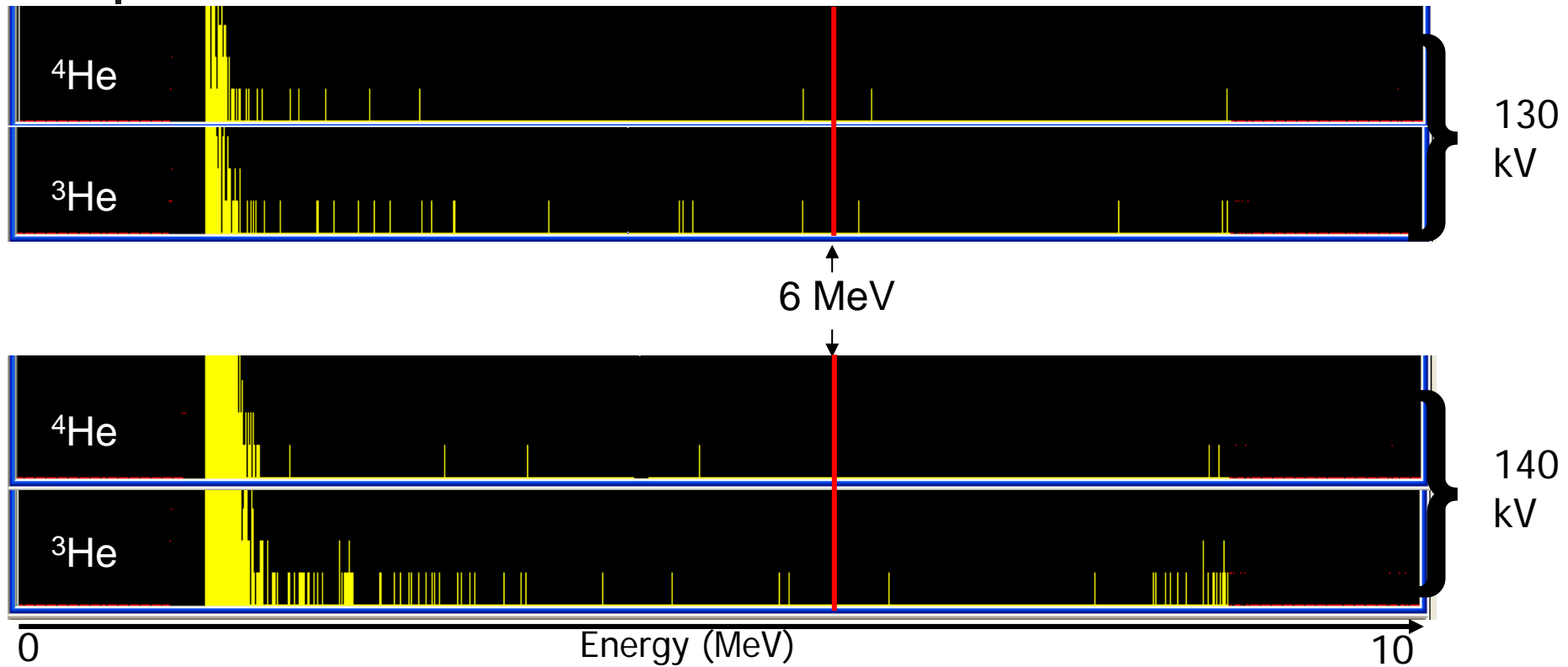
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Actual Spectra— ^3He at 140 kV 25 mA 900 sec with 2nd Generation Arc Suppression



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

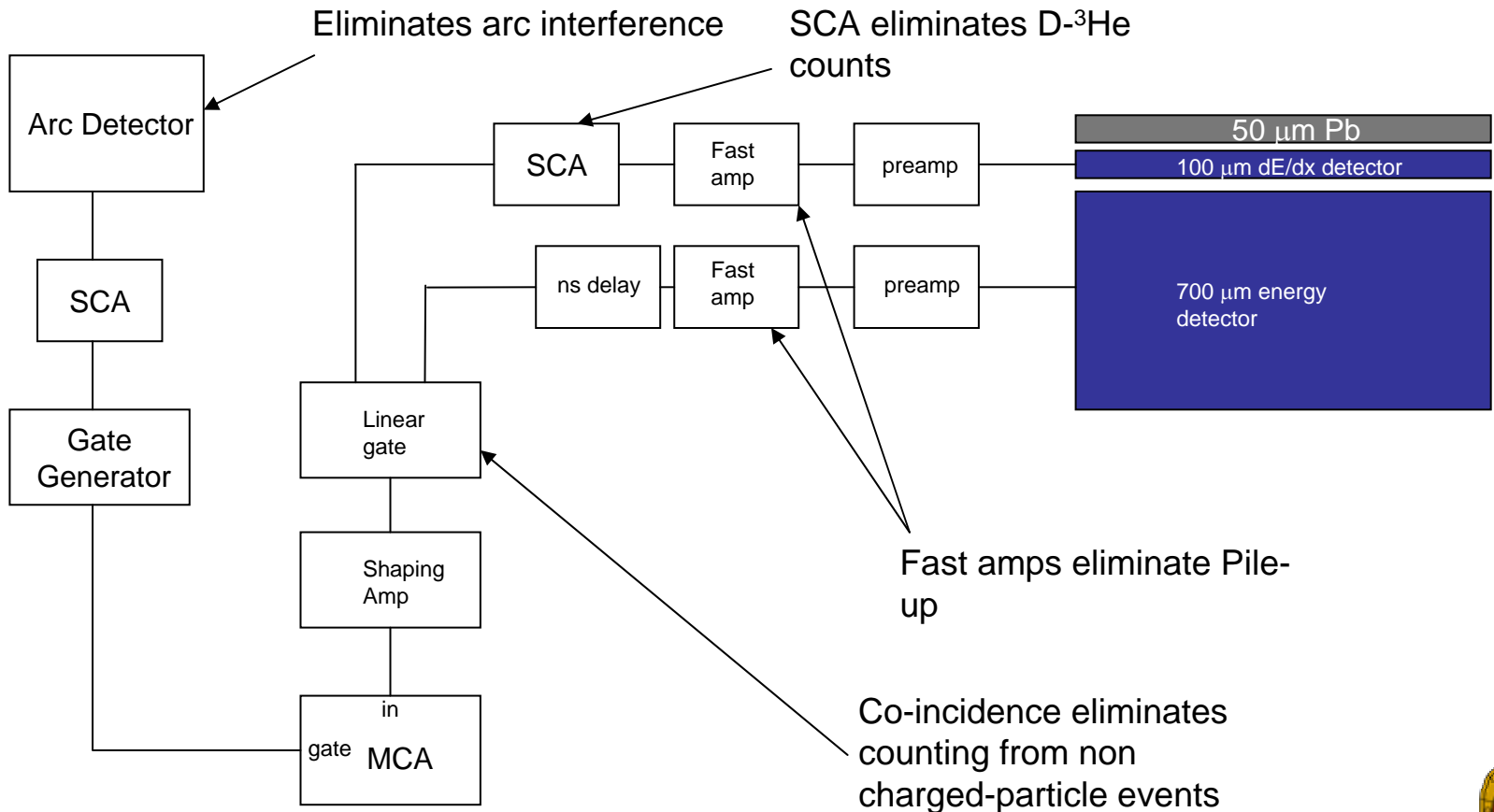


Detection has Come a Long Way—More can be Done

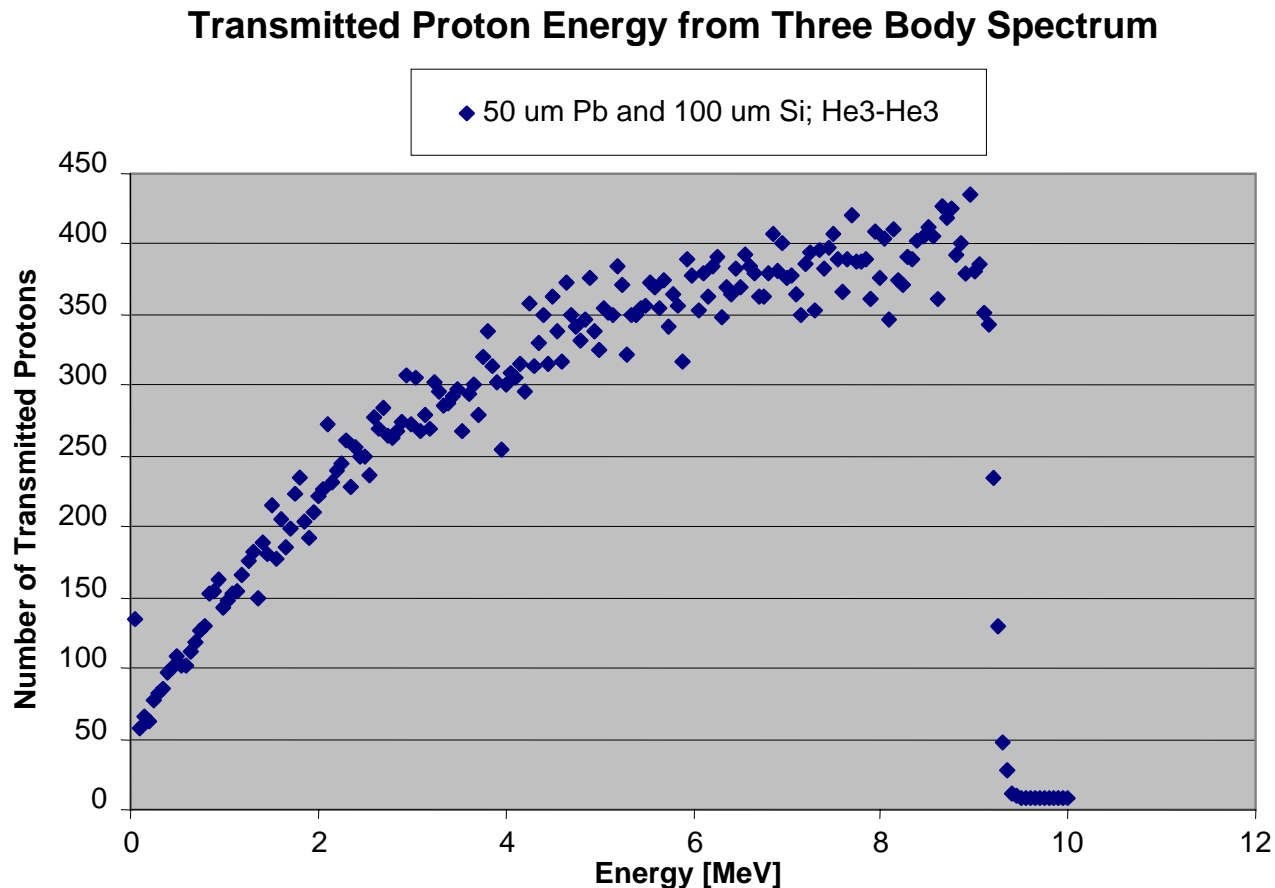
- Even though the arcs have been effectively suppressed, there are still multiple sources of noise
 - Background radiation
 - Pile-up noise
 - Induced radiation from surrounding experiments
 - Interference from D-³He due to impurities containing the natural abundance of D (about 1 per 6000 H atoms)
-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



Third Generation Arc Suppression Circuit



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



55% of incident ions detected by new setup





Summary

- IEC operating conditions necessary to observe ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$ 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 ${}^3\text{He}$ gas versus ${}^4\text{He}$
- Third generation detector setup will allow data to be interpreted more clearly and with better statistics

