Development of Heavy Ion Beam Probe Detector Elements with a Direct View of the Plasma

T. P. Crowley
P. J. Fimognari, D.R. Demers
Xantho Technologies, Madison, WI

PLASMA
NO ION BEAM

FUTURE WORK

- Materials & surface preparation
  - Lower UV-induced photo-emission
  - Detector surfaces & surrounding structure
- Plasma + ion beam
  - Stop plasma ions at front
  - use present detector in back
- Magnetic suppression

SUMMARY

- Alternate approach to Heavy Ion Beam Probe
  - Smaller
  - Less expensive
  - Different capabilities
  - Easier implementation
  - Lower cost
- Replace energy analyzer with detectors that directly view plasma
- Increased noise
  - UV
  - plasma particles
  - Can we suppress noise?

DIRECT VIEW HIBP

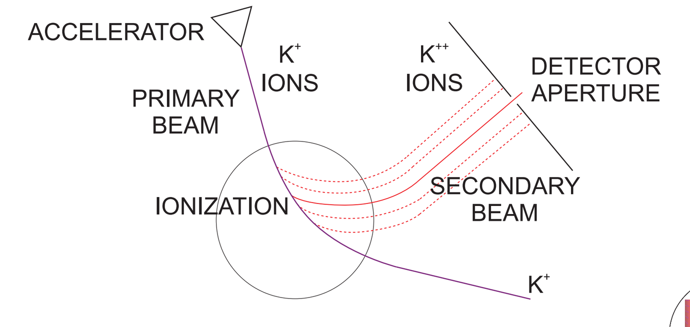
ADVANTAGES

- New capabilities
  - Velocity detector for A_s and B_{pol} measurement
  - Array detector for fluctuation studies
- Easier implementation
  - Much smaller detector
  - Flexible detector location
- Lower cost
  - Lower energy accelerator
  - Smaller secondary Larmor radius
  - No analyzer

DISADVANTAGE

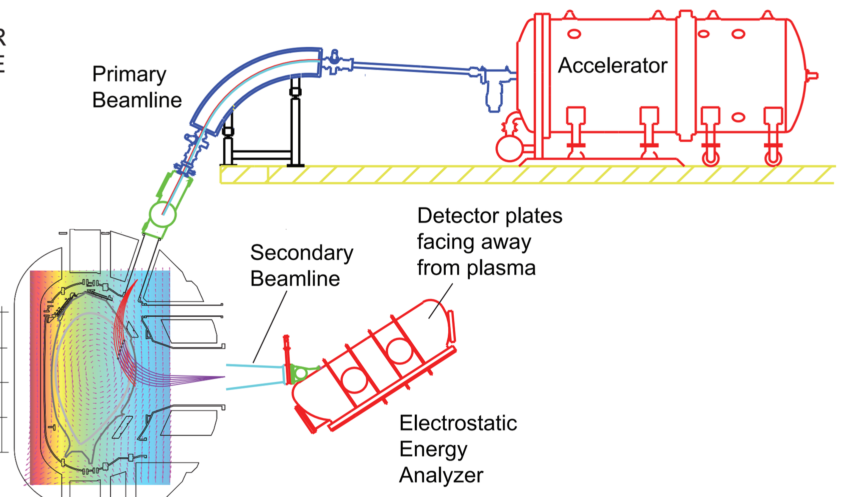
- Loss of φ, $\tilde{\varphi}$, measurement capability

HIBP OVERVIEW

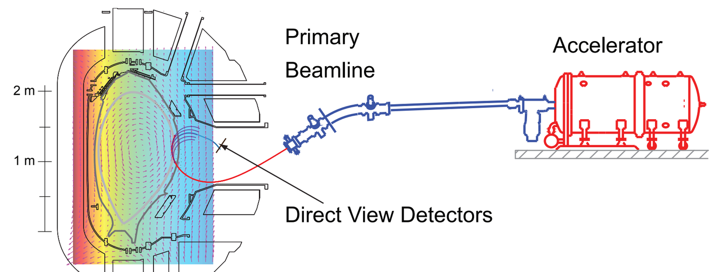


- HIBP typically measures φ, $\tilde{\varphi}$, $\tilde{n}/n$
- Inject primary (1+) ions
- Detect secondary (2+) ions
- Measurements spatially localized to ionization point

TRADITIONAL HIBP

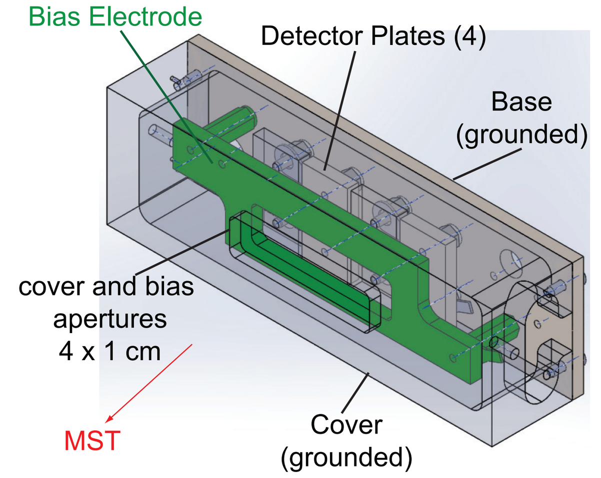


DIRECT VIEW HIBP



EXPERIMENTS

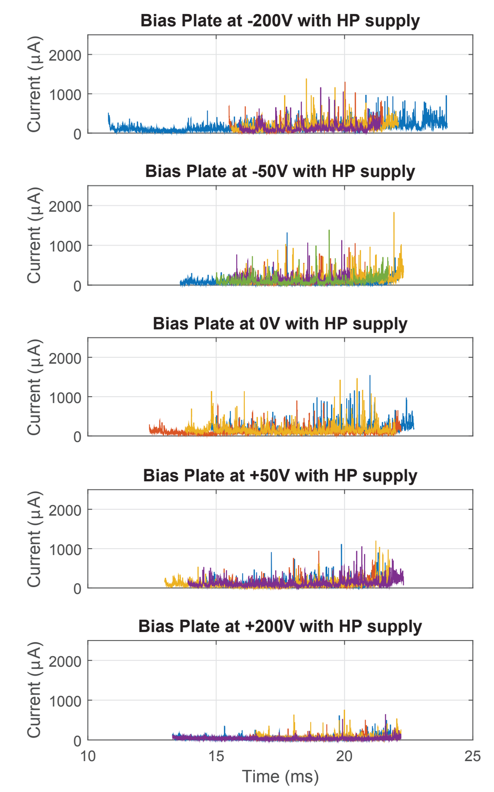
DETECTOR

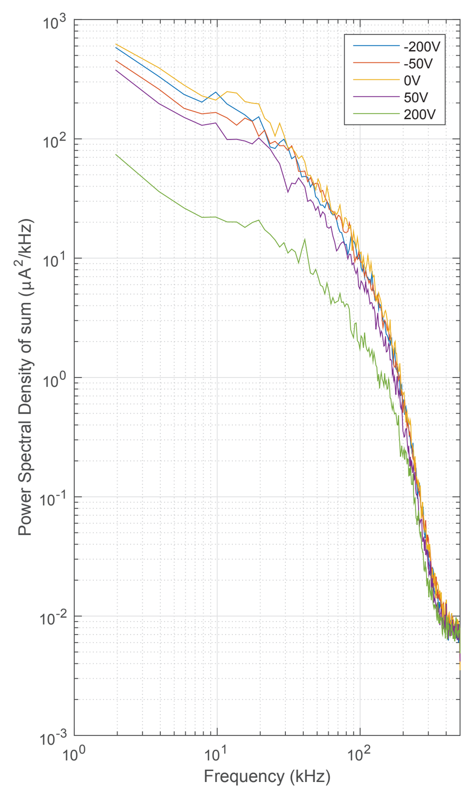


SETUP

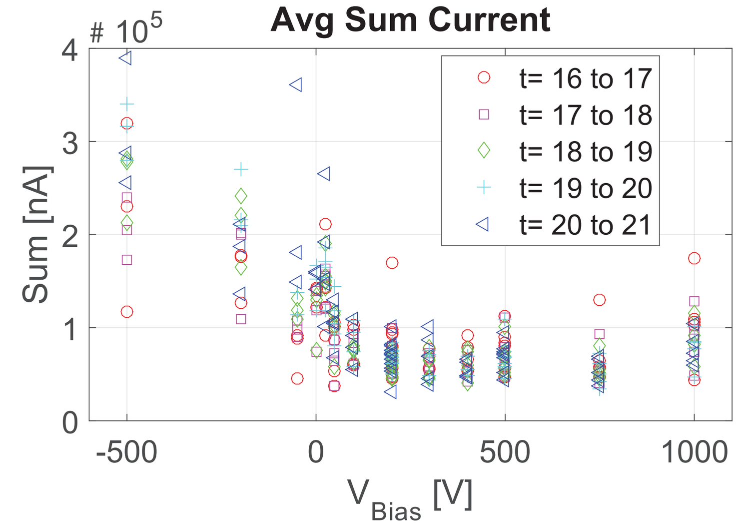
- Detector in MST HIBP secondary beamline
  - ~ 40 cm from edge of plasma
  - View through 4.5" port with magnetic 'keeper'
  - (keeper deflects plasma electrons & low energy ions)
- Bright UV source
- B-field outside vacuum chamber small
  - free streaming plasma particles
  - 'natural' magnetic suppression not present
- Data taken during 400 kA and 500 kA PPCD plasmas
  - (pulsed parallel current drive)
  - relatively low UV noise
  - t = 16-21 ms time period
- 4 currents measured (1 per plate)
- Trans-impedance amp gain = 10^5 to 10^7

DETECTOR FACING PLASMA





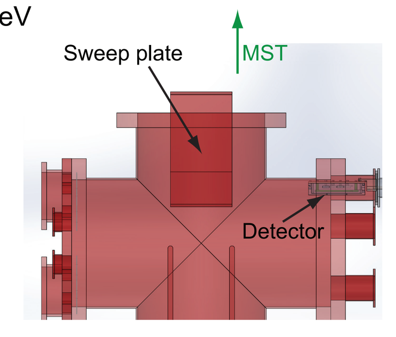
- Large positive current signal - 100s of μA
  - Typical HIBP signal 100 nA
- Spiky signal
- Reduce with positive bias electrode
  - need 100s V
  - Increase with negative bias electrode

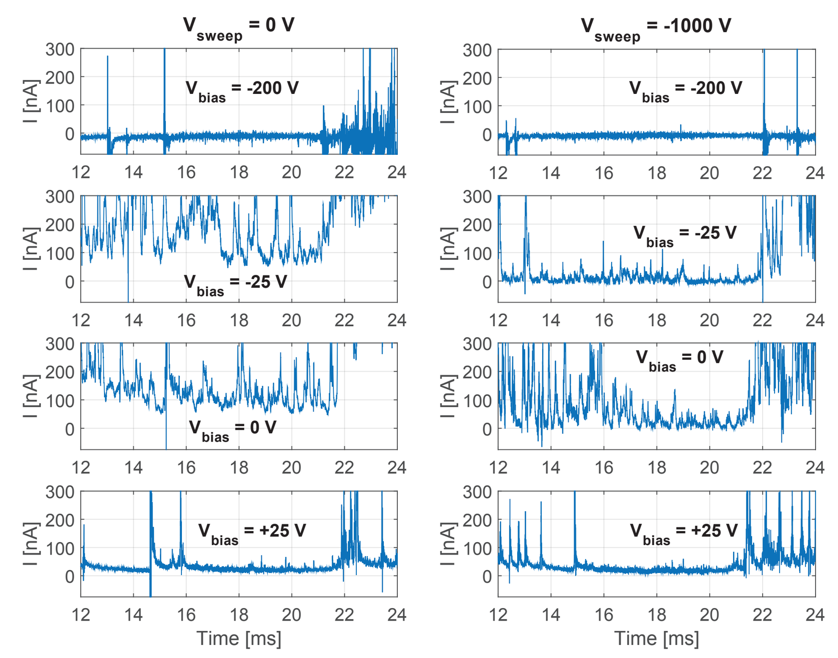


- Conclusion:
  - Positive plasma particles
  - Energy up to 100 eV or more
  - Not UV-induced

DETECTOR FACING AWAY FROM PLASMA

- Larger ratio UV to plasma particles
- Smaller signals: 10 -> 100s of nA
- Reduce with +25 V bias
  - signal now looks like HIBP noise due to UV
  - Reduce with -200 V bias
  - Reduce with negative bias on nearby plate
  - (attracts positive particles)
- Conclusion (tentative):
  - UV-induced component
  - Positive plasma particles -
  - < 10 eV





SIGNALS AND NOISE

SIGNAL

- HIBP ion impacts metal plate
  - nA current level
  - positive current
- Secondary electrons amplify signal (x1 -> x10)
  - positive current
  - (can also contribute to noise)
- High gain (~10^7) transimpedance amp

NOISE

- Secondary electron from other surface
  - (detector plate or other)
  - negative current
- UV-induced photoemission from detector
  - positive current
- UV-induced photoemission from other surface
  - negative current
- plasma particles impacting detector
  - positive or negative current
- electronic noise of amps
- electrical pickup noise
- Most worse for direct view HIBP

NOISE SUPPRESSION

POSITIVELY BIASED ELECTRODE

- Reduce positive plasma particle impact
  - reduce positive noise current
- Attract secondary electrons from other surfaces
  - reduce negative noise current
- Attract UV-induced photoemission from other surface
  - reduce negative noise current
- Bias electrode emits secondary electrons
  - adds to negative noise current

NEGATIVELY BIASED ELECTRODE

- Push UV-induced photoelectrons back to emission surface
  - reduce positive noise current
- Reduce negative plasma particles
  - reduce negative noise current
- Push detector's secondary electrons back to plate
  - decreases amplification effect

MAGNETIC

- UV-induced photoelectrons return to emission surface
  - reduce positive or negative noise current
- Reduce plasma particles, especially electrons
- Keep secondary electrons from other surfaces away
  - reduce negative noise current
- Push detector's secondary electrons back to plate
  - decreases amplification effect

CONCLUSIONS

- Less expensive, easier to implement HIBP under development
- Requires detectors that directly view plasma
- New capabilities
  - arrays
  - velocity detector
- Tests on MST
  - Large current from plasma particles
  - Will need to suppress with positive bias or magnetic fields

Control of secondary electrons from ion beam impact using a positive potential electrode

ION BEAM
NO PLASMA

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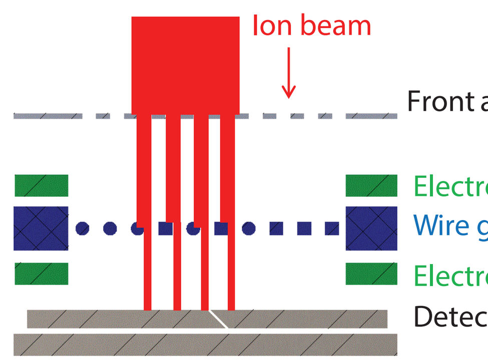
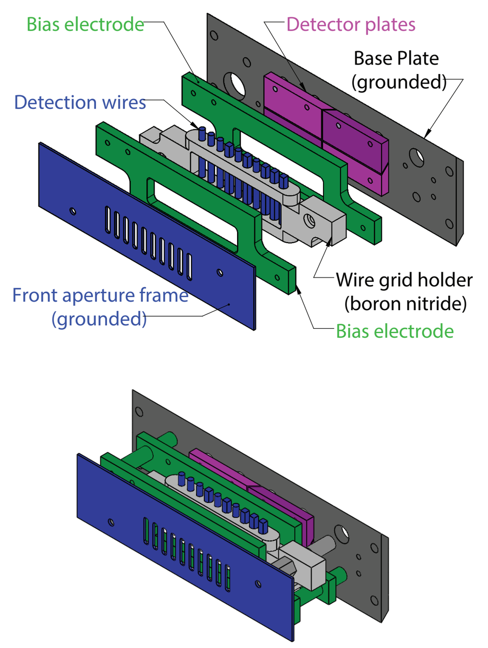
BACKGROUND

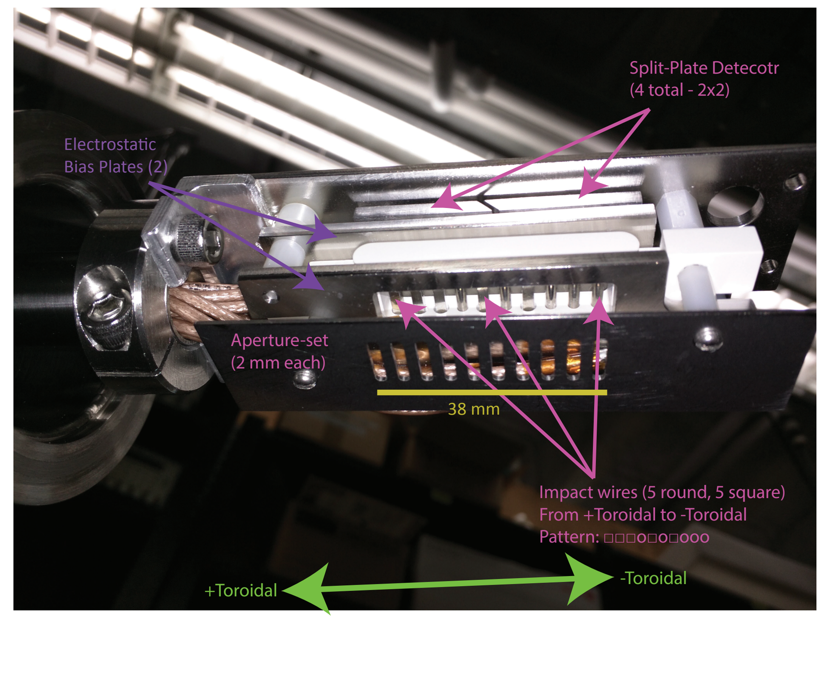
- HIBP signals - currents when beam impacts plate / wire
  - Secondary electrons emitted
  - Good - multiplies signal
  - Bad - if electron strikes different detection plate
    - more likely with velocity detector
    - not large problem for standard enegy analyzer
- Previous work - negatively biased electrodes
  - Push electron back to original surface
  - Loses signal mutliplication advantage
- Nedzelskiy, et al., Rev. Sci. Instrum. 72, 575 (2001)
  - -100 V electrode to suppress secondary electrons
- Beckstead, et al., Rev. Sci. Instrum. 68, 328 (1997)
  - -300 V electrodes / wires to suppress photoelectrons (UV) and secondary electrons

APPARATUS



$$v_x = v_y \tan\beta \, \frac{i_{wire} - i_{plate}}{i_{wire} + i_{plate}}$$





- Front aperture grid forms beamlets
  - Wire grid displaced by 1/2 opening
  - % of beams on wires / plates --> beam angle
  - beam angle -> v_{tor} -> A_{tor}

EXPERIMENT

SETUP

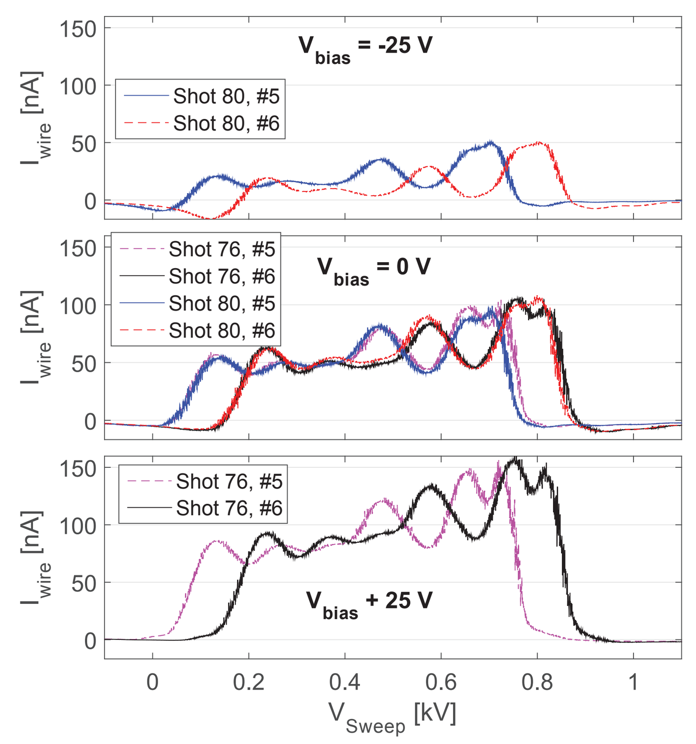
- Velocity detector in MST primary beamline
- Constant angle / variable position sweep
  - Non-uniform beam profile
- Currents from 10 wires and 4 plates
  - trans-impedance amp - 10^7 gain
- Signals in figure - wires 4 mm apart

KEY FEATURE

- Negative current -
  - secondary electrons from neighboring wires / plates
  - (e.g. wire 6 at V_{sweep} = 0.12 kV)
  - Secondary electon effects masked at other V_{weep}
  - lowers current

MAIN RESULTS

- Negatively biased electrode
  - Pushes secondaries back toward wire plane
- Wire # 5 signal drops
  - (loss of amplification)
- Wire # 6 more negative
  - more of #5's secondaries
- -25 V not strong enough to push to original surface
- Positively biased electrode
  - Pulls secondaries away
  - #5 and #6 signal larger
  - #6 positive
  - small negative current at some sweeps
- Advantages
  - Keep signal multiplication
  - Larger current
  - Lower bias voltage (magnitude) required
- Disadvantages
  - Cannot suppress UV-induced photoelectrons



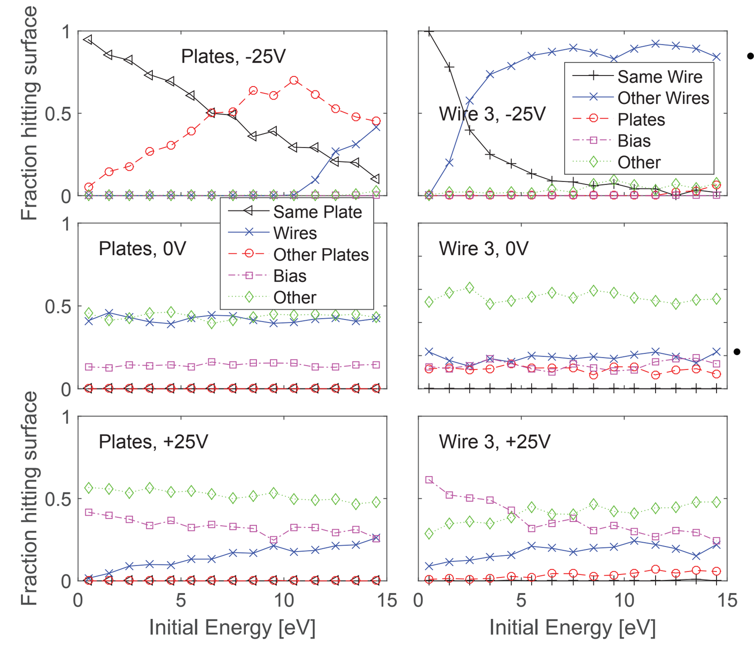
ADDITIONAL RESULTS

- Amplification factor - κ ~ 7 +- 3
  - Estimate from ratio of +25 to -25 total current
- - 100 V -> still negative current - not as much
- + 100 V slight improvement
- Easier for #5 secondaries to hit #6 than vice versa
  - Observable in signal

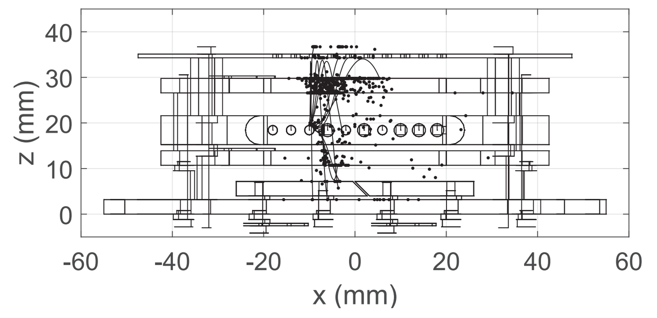
CONCLUSIONS

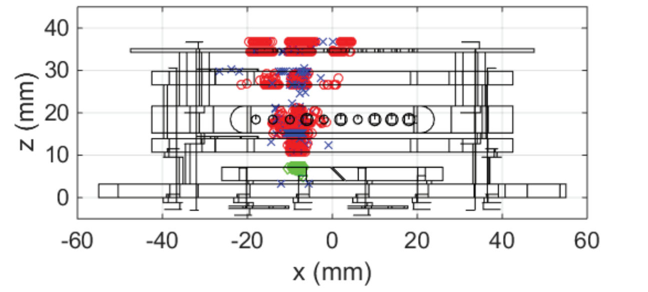
- Small positive bias can direct secondary electrons away from detector surfaces
- amplifies signal
- reduces secondaries that propagate to other detector
  - reduces signal error

MODELING



Trajectories with +25 V Bias





End points of trajectories originating on split-plate

SETUP

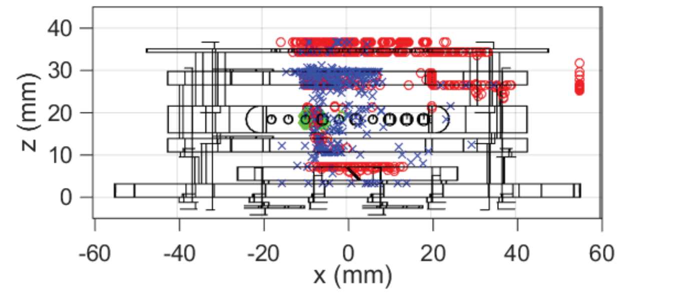
- Finite-element simulation of electric potential (3D)
  - Monte-Carlo model of secondary electron trajectories (3D)
  - Emission surfaces - 1/2 wire, plate strip
  - specular reflection + broadening
  - electron energies - 0 to 15 eV

RESULTS

- Negative bias
  - Most secondaries back to original plane
  - Lower signal
  - Many go from one wire/plate to another
    - OK for velocity measurement
    - Error in position measurement
  - Differs from measurement
    - total plate and wire current in experiment can be negative
- Positive bias
  - Most secondaries do not hit a detector
  - Larger signal
  - Still a remnant that propagates from one to another
  - Introduce error in velocity measurement

◇ -25 V Bias
o 0 V Bias
x +25 V Bias

End-points of secondaries originating from wire 3



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